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Energy Security:
Trends, concerns and conflicts.
The case of China.

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Contents

Abstract

The year 2015 was widely characterized by political debates and governmental support to renewable energy. Solving the energy crisis has become a highly discussed topic and strategic goal by global leaders, concerned about political and environmental issues. Reducing dependence on fossil fuels and on fossil fuels exporters as well as addressing global warming and climate change issues are considered between the top objectives worldwide; that is the reason why researchers and scientists around the world are involved in search for such renewable energies capable to replace fossil fuels and to self-replenish over time. The boom of renewable energies worldwide has been largely possible due to growing demand for energy, new high profile agreements and dedicated polic support initiatives, (such as better access to financing, cost-competitiveness of renewable technologies, energy security) and environmental concerns. This has resulted in improved energy efficiency and accessibility to renewable energy. Global investments in renewable energy recorded high figures, and investments in developing countries oversaw the industrialization process. Despite a drop in the global fossil fuel prices, renewable energy capacity consumption has witnessed an increasing trend, and direct and indirect employment in the renewable sector has boosted (REN21, 2016). This shows clear commitment to renewable energy deployment, strong international consensus and, even if humanity is not ready yet to abandon once for all fossil sources of energy, willingness of energy transition away from fossil fuels is under way. Among the leading countries in production and consumption of renewable energy, China is a unique case. Specifically, it appears in the top countries for hydro, solar, wind and bio-energy production and electricity consumption. China has in fact increasing need for energy caused by growing population and economic development, and ways to reduce fossil fuels dependence is crucial for the country. This thesis tries to analyze the impact of renewable energy consumption on China's GDP per capita. The Instrumental Variable methodology is approached initially to establish a correlation between non-renewable energy prices and renewable energy consumption, and in turn GDP per capita. Further, the thesis attempts to show a causal relationship between renewable energy consumption and GDP per capita in the long run through a Vector Error Correction Model.

Key words: Renewable Energy, Energy Security, GDP, China.

List of acronyms

AREI	African Renewable Energy Initiative
Bcm	Billion cubic meters
BN	Billion
BNEF	Bloomberg New Energy Finance
BP	British Petroleum
CBM	Coalbed methane
CNOOC	China National Offshore Oil Corporation
CNPC	China National Petroleum Corporation
CO2	Hydrocarbon
COP21	21st Conference of the Parties
CVF	Climate Vulnerable Forum
CYG	Coal-to-gas
EC	European Commission
EPA	Environmental Protection Agency
ESPO	Eastern Siberia-Pacific Ocean
EU	European Union
FGE	Facts Global Energy
FITs	Feed-in tariffs
FSRU	Floating storage and regasification unit
GDP	Gross Domestic Product
GMM	Generalized Method of Moments
Gt	Giga tons
GW	Gigawatt
IEA	International Energy Agency
IEO2014	International Energy Outlook 2014
ISA	International Solar Alliance
IV	Instrumental Variables
KMG	Kaz Munay Gas
LIML	Limited Information Maximum Likelihood
LNG	Liquefied natural gas
MBtu	Million British Thermal Unit
Mt	Million Tons
Mtoe	Million Tons of Oil Equivalent
MW	Megawatt
NOC	National Oil Companies
OECD	Organization for Economic Co-operation and Development
OLS	Ordinary Least Square
OPEC	Organization of the Petroleum Exporting Countries
PV	Photovoltaic system
REN21	Renewable Energy Policy Network for the 21st Century
SDGs	Sustainable Development Goals
SE4All	Sustainable Energy For all
SINOPEC	China Petroleum and Chemical Corporation
SNG	Synthetic natural gas
SPR	Strategic petroleum reserve
Tcm	Trillion of cubic meters
TPES	Total Primary Energy Supply

TWh	Terawatt hour
UK	United Kingdom
UN/DESA	United Nations Department of Economic and Social Affairs
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change’s
UNGA	United Nations General Assembly
US	United States
WEF	World Economic Forum
WTI	West Texas Intermediate
WTO	World Trade Organization

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Introduction

The energy sector is important for global economic activity because it creates employment and value due to the extraction, transformation and distribution of energy goods and services. Moreover, it represents the fuel of a country's development and population well-being as it constitutes an input to almost every product and service around the world. Energy demand has risen in the past decades, and is expected to increase by 21% by 2030 (IEA, 2015). In fact, as population expands more energy is needed to support people's necessities and increasing living standards, and thus the production of energy has boosted. Although higher energy demand has been initially fulfilled by fossil fuels-based energy production, this has aggravated environmental problems such as pollution and climate change. Despite fossil fuels are still the major contributors to energy production, countries around the world are searching for solutions able to improve economic performance while decreasing harmful emissions (IEA, 2016). Renewable energies are also useful in energy diversification.; in fact, the supply of energy should be certain to meet energy security and accessibility standards, i.e. the uninterrupted, safe and affordable minimum amount of energy needed to comply with economic activities and public services. According to REN21, public support for renewable energy has widely increased within countries, and governments worldwide have sustained its deployment through policies promoting investments and renewable capacity, technologies and infrastructures. Higher and higher targets regarding renewables deployment were established and meet by countries around the world in 2015 (REN21, 2016). From 2014, low fossil fuels prices have risen the concern that renewable energy would have suffered from increased price-competitiveness of fossil fuels. According to REN21, it did not happen due to diminished costs and increased efficiency of renewable energy technologies. On the contrary, investments in the renewables sector has boosted to a new record (BNEF, 2016), renewable capacity increased worldwide and cost-effectiveness of the technologies increased (REN21, 2016).

This thesis aims at deeply analyze the energy sector, in particular the renewable energy one. Specifically, the main objective is to capture and measure the impact of renewable energy consumption on economic growth in China through an econometric analysis. China has been chosen because it represents a particular case. Since 1980 it underwent the fastest major economic expansion in history (World Bank, 2014). Increasing economic and population growth have made China the major consumer of energy as well as the bigger contributor to pollution and climate change worldwide. Increased concerns about environmental issues and fossil fuels scarcity have fostered China's implementation of renewable energy across the country (IEA, 2015). In 2015, China emerged as the major investing country in renewables (BNEF, 2016). Huge investments in the sector have been sustained by effective policy measures and government support (REN21, 2016).

The analysis of the impact of renewable energy consumption on China's GDP per capita resulted to be interesting given the unique case represented by the country. The Instrumental Variable methodology is approached to establish a correlation between non-renewable energy prices and renewable energy consumption, and then GDP per capita. Further, the thesis attempts to show a causal relationship between renewable energy consumption and GDP per capita in the long run through a Vector Error Correction Model.

1. World Energy Market Overview

Energy markets are commodity markets related to the generation, distribution and consumption of energy. According to the Renewable Energy Policy Network for the 21st Century, in the past few years, the world energy market is moving towards renewable energies. In fact, considering the severe environmental problems that the world is facing, renewable energy is considered the more efficient way to address pollution and climate change since it is becoming cheaper and more effective (REN21, 2016). Moreover, increasing renewable energy capacity can mitigate a country's dependence from fossil fuels and from fossil fuels producing nations (REN21, 2016).

According to the International Energy Agency, in the last decades, energy market trends has been widely influenced by factors such as economic and population growth (IEA, 2016). Moreover, according to Bloomberg New Energy Finance, from summer 2014 prices in the market sector has changed and has modified supply and demand, as well as trade (BNEF, 2016).

According to IEA, economic growth is highly related to energy trends because countries need increasing quantity of energy to develop, build and maintain infrastructures and support its businesses; for these reasons, the link between energy demand and economic development has appeared to be strict. Global economy is finally stabilizing after the financial crisis and is expected to grow between 3 and 4 percent in the 2015-2020 period, especially due to emerging markets and developing countries. Developing nations are expected to grow at a higher percentage than 4%, accelerating global economic growth (IEA, 2015).

Population growth has also a great impact on energy demand because growing populations need increasing quantities of food and energy to meet their needs and develop (IEA, 2016). According to the United Nations Department of Economic and Social Affairs, the current global population of 7.3 billion is expected to reach 8.5 billion in 2030, 9.7 billion by 2050 and 11.2 billion in 2100 (UN/DESA, 2015).

The increasing production and consumption of energy has led to high greenhouse emissions, climate change, air, water and land pollution (IEA, 2015). According to IEA, human activities regarding the consumption of energy are the main responsible of emissions. To address environmental issues, countries around the world are supporting renewable energy deployment through investments in new and more effective technologies and policies (IEA, 2015).

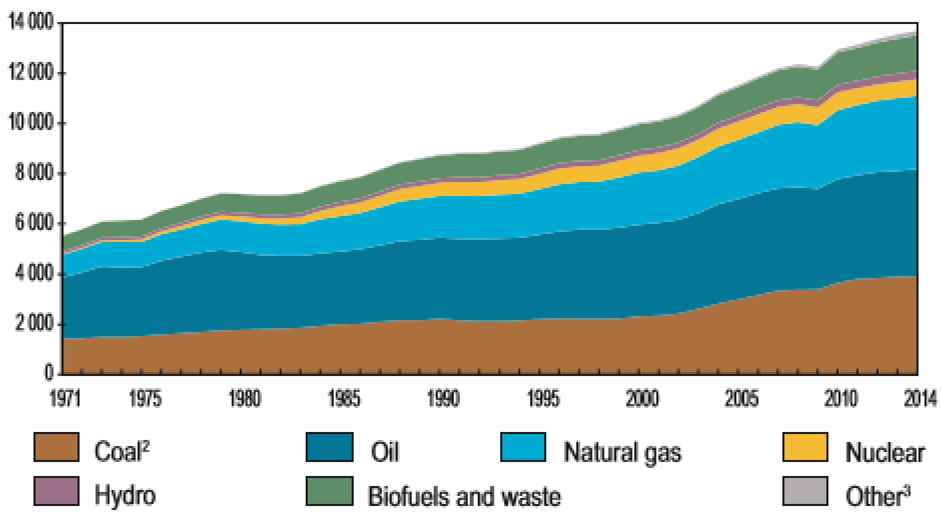
Finally, according to IEA, the year 2014 has seen oil prices decreasing to unsustainable low levels. They were cut in half in just six months, and they are still low now. This constitute a big problem for the energy sector and will influence energy trends in future. Oil price is expected by IEA to rise and balance the market again in 2020, but if it stays low for longer, it could change the worldwide political scenario (IEA, 2015).

1.1. Energy production

Primary energy is a form of energy found in nature, an energy that has not been subjected to any transformation process. It can be renewable and non-renewable; crude oil, coal, natural gas, nuclear, hydro, biofuels and waste, geothermal and other typologies of energy extracted from the ambient environment are called primary energy (IEA).

Total primary energy supply (TPES) indicates the sum of production and imports subtracting exports and storages.

Figure 1.1:Total TPES from 1971 to 2014 by fuel (Mtoe).

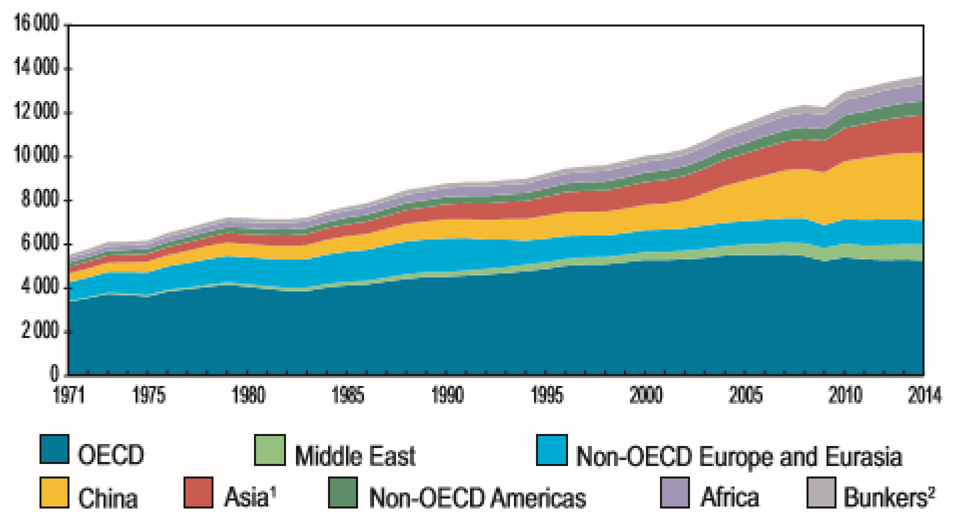


Source: Key World Energy Statistics 2016, IEA.

Figure 1.1 shows total production of energy from 1971 to 2014. It shows that oil is the most popular energy source and it is followed by coal and natural gas. Nowadays, countries are trying to use less oil they can, given its scarcity, but it remains the most common energy source worldwide (IEA, 2016).

According to IEA, total primary energy production has increased by 7,598 Mtoe from 1973 to 2014, from 6,101 Mtoe to 13,699 Mtoe. In 2015, total primary energy production increased by 0.8% with respect to the year before, the lowest recorded since 1999, except for the recession in 2009. Oil and biofuels and waste production have declined from 2013 to 2014, respectively from 46.2% to 31.3% and from 10.5% to 10.3%. On the contrary, coal production rose from 24.5% in 2013 to 28.6% in 2014, natural gas increased from 16% to 21.2%, nuclear rose from 0.9% to 4.8%, hydro increased from 1.8% to 2.4% and geothermal, solar and wind increased from 0.1% to 1.4%. This shows an attempt to move forward a greener and sustainable production of energy and concerns about oil scarcity (IEA, 2015/2016).

Figure 1.2: World total energy supply from 1971 to 2014 by region (Mtoe).



Source: Key World Energy Statistics 2016, IEA.

Figure 1.2 shows total energy production by region during the period between 1971 and 2014. According to IEA, OECD countries represented the major producers of energy worldwide (38.4% of the world total 13699 Mtoe), followed by China (22.4%), the rest of Asia (12.7%), non-OECD Europe and Eurasia (8.2%), Africa (5.6%), Middle East (5.3%), non-OECD Americas (4.7%) and international aviation and marine bunkers (2.7%) in 2014. OECD countries lead the rank because six of OECD's members appear in the highest ten energy producing countries, which are UK, Japan, Norway, South

Korea, Germany and US. As regards of China, even if its energy production had increased a lot in the last 15 years, it has recently slowed its trend (IEA, 2016).

According to IEA, China's energy production has boosted between 1973 and 2014, growing from 7% to 22.4%. OECD countries alone produced 3,740 Mtoe of energy in 1973, and 5,269 Mtoe in 2015. They can be split up into three sub-groups, OECD Americas, OECD Europe and OECD Asia Oceania. In 1973, total OECD production amounted to 3,740 Mtoe, of which 11.1% were produced by OECD Asia Oceania, 36.8% by OECD Europe and 52.1% by OECD Americas. In 2015, total energy production in OECD countries were 5269 Mtoe. OECD Americas and Europe amounted to 50.9% and 32.3% respectively, while OECD Asia Oceania produced 16.8% of total OECD countries' energy production (IEA, 2016).

Fossil and Nuclear Energy

Fossil fuels are those fuels formed by natural processes, which transform buried dead organisms in a source of energy for humanity. Fossil fuels typically take millions of years to form, and for this reason are considered non-renewable. They include crude oil, coal and natural gas.

Crude oil remains the leading energy source worldwide, and contributed to 36.1% of world total energy production in 2015 and 47.2% of world total final energy consumption in 2014 (IEA, 2016). It is considered the most efficient and cost-effective source of energy that humanity is able to use. According to IEA, no energy source that can substitute petroleum has been discovered yet; crude oil would continue to be the top energy source for decades (IEA, 2015).

In 2015, coal accounted for 18% of world total energy production and, in 2014, 3.1% of world total energy consumption (IEA, 2016). Its importance is growing since it is cheaper and more abundant than crude oil. According to REN21, coal trend has slowed down only in 2015 (REN21, 2016).

Natural gas contributed to 26% of world total energy production in 2015 and 20.3% of world total energy consumption in 2014 (IEA, 2016). According to IEA, global gas demand growth slowed since 2012, from average growth of 2.2% a year to 1.0% (IEA, 2015).

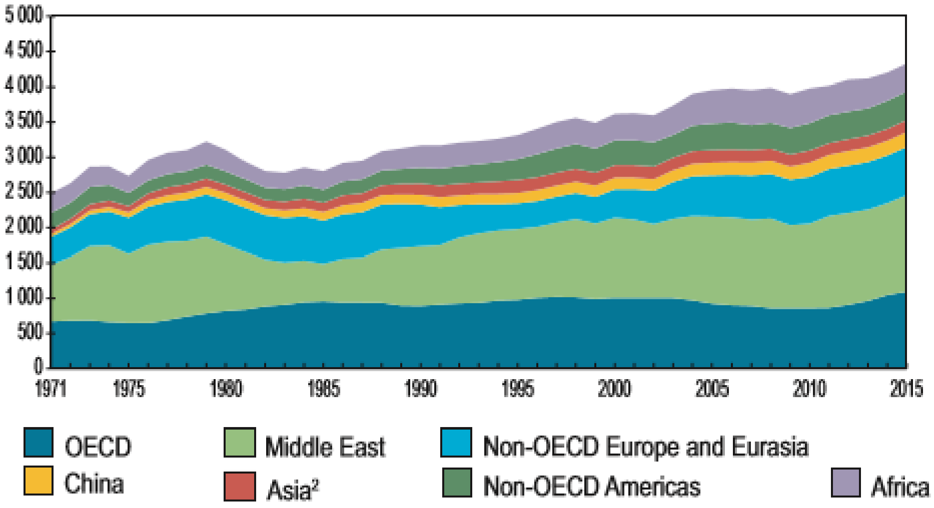
Nuclear energy is derived from nuclear reactions. This technology uses the energy released by splitting the atoms of particular isotopes of uranium or plutonium to generate heat and electricity. According to IEA, 9.8% of global energy production derived from nuclear power reactors in 2015. Even if this kind of energy is considered to be one of the most controversial because of the risk at which it submits the human kind, other 60 reactors was constructed in 2015.

Crude oil

According to British Petroleum (BP), 47.3% of the world's proven oil reserves are located in Middle East. Proved reserves of crude oil are taken to be "those quantities that geological and engineering information indicates with reasonable certainty can be recovered in the future from known deposits under existing economic and operating conditions" (IEA). According to BP, the highest proved oil reserves in 2015 are in Venezuela (17.7% of total), Saudi Arabia (15.7%), Canada (10.1%), Iran (9.3%), Iraq (8.4%), Kuwait (6%), United Arab Emirates (5.8%), Libya (4%), US (3.2%), Libya (2.8%), Nigeria (2.2%), Kazakhstan (1.8%), Qatar (1.5%), Brazil (0.8%) (BP, 2016). Total world reserves in 2015 amount to 239.4 thousand million tons (BP, 2016).

Oil extraction is the process used to remove the usable petroleum from the Earth, and is very expensive and delicate. The oil field must be located using seismic surveys; then, the oil well is created by drilling a long hole into the ground. Moreover, not all the oil can be extracted from the Earth due to limitations in extraction technologies, and only the portion of oil that can be brought to the surface is considered producible or reserves. Despite new technologies are far more precise than previous ones, many oil-producing countries do not reveal exact data about oil reserves for political reasons. Oil rich countries can set the oil price as they prefer and can enjoy bargaining power over countries seeking their resources. High corruption causes oil data to be omitted and oil producers to take advantage of their unique position; They can set high prices or threat to restrict exports. All the countries around the world depend on, and demand huge quantities of oil and this guarantees political and economic power to nations endowed with oil against those that are not. In order to maintain that power, oil rich countries are not open to foreign oil investments, even if huge efforts are made to reform the standard patterns of engagement with oil rich countries.

Figure 1.3: world total energy supply from 1971 to 2014 by region (Mtoe).



Source: Key World Energy Statistics 2016, IEA.

According to IEA, countries in Middle East alone accounted for 31.5% of global oil production in 2015, followed by OECD countries with 25.3%, non-OECD Europe and Eurasia with 15.2%, non-OECD Americas with 9.4%, Africa with 9.1%, China with 5% and the rest of Asia with 3.9%. Total oil production in 2015 amounted to 4,331 Mt (IEA, 2016). According to IEA's provisional data, in 2015 more than 67% of world oil production came from the top ten countries: Saudi Arabia 572 Mt (13.2%), United States 567 Mt (13.1%), Russia 533 Mt (12.3%), Canada 221 Mt (5.1%), China 215 Mt (5%), Iraq 175 Mt (4%), Iran 168 Mt (3.9%), ,United Arab Emirates 160 Mt (3.7%), Kuwait 160 Mt (3.7%) and Venezuela 144 Mt (3.3%) (IEA, 2016).

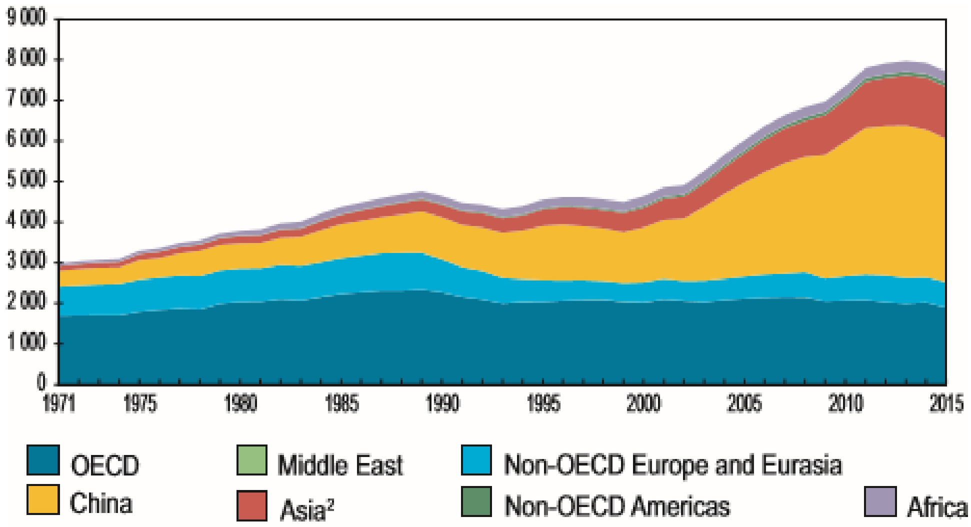
As stated by IEA (IEA, 2016), the top ten net oil exporters in 2014 were Saudi Arabia (354 Mt), Russia (222 Mt), United Arab Emirates (125 Mt), Iraq (124 Mt), Nigeria (111 Mt), Canada (104 Mt), Kuwait (101 Mt), Venezuela (91 Mt), Angola (81 Mt) and Kazakhstan (64 Mt).

Coal

According to IEA, coal has become critical in the world's energy growth. It accounted for 65.5% of world's electricity generation and commercial heat and 83.2% of electricity generation in OECD countries in 2014. Power plants that use coal as resource produced high percentages of electricity. This increasing need for coal has made it one of the leading energy sources. Moreover, coal is more affordable, widely distributed and undoubtedly more abundant than crude oil. Despite that, world coal production started to decline in 2014, and saw its largest decline in absolute terms in 2015, since IEA records began in 1971. According to IEA, "This decline was the result of a multitude of factors, from programmed deliberate phase out of coal use in countries such as Denmark, France and the United Kingdom, to curtailing overproduction and setting quotas for mine operating days in the People's Republic of China, to falling demand for coal produced in the United States, both domestically and internationally." (IEA, p.3, 2016). According to IEA, international trade declined too due to a 6% fall in imports and 4.1% decline in exports. China and India, the two biggest importers, highly decreased their imports and relied more on domestic production, and exports declined compared to the record level of 2014, but still represent an increase of 22.1% over 2010 levels (IEA, 2016).

According to BP, total coal reserves worldwide were estimated at 891,531 million tons in 2015, sufficient to meet around 114 years of global production at the current rate. The major share al natural gas reserves are located in Europe and Eurasia, totaling 34.8% of total (BP, 2016). Proved reserves of coal are taken to be "those quantities that geological and engineering information indicates with reasonable certainty can be recovered in the future from known deposits under existing economic and operating conditions" (IEA). According to BP, the highest proven coal reserves were in United States (26.6% of global total), Russia (17.6%), China (12.8%), Australia (8.6%), India (6.8%), Germany (4.5%), Hungary (3.8%), Ukraine (3.8%), South Africa (3.4%), Indonesia (3.1%) and Serbia (1.5%) (BP, 2016).

Figure 1.4: coal production from 1971 to 2015 by region (Mt).



Source: Key World Energy Statistics 2016, IEA.

According to IEA (IEA, 2016), the global production of coal grew rapidly between 1972 and 2013, from 3 Gigatons (Gt) in 1972, 5 Gt in 2003, 7 Gt in 2010 and around 8 Gt in 2013, especially due to China. Since 2000, production in China has continued to increase by 160.3%, even though it fell by 5.9% since 2013. Chinese production of coal in 1973 were 13% of total (3,074 Mt), in 2015 it rose to 45.8% of global production (7,709 Mt). Percentage of coal production in OECD countries used to be the highest (55.6%) in 1973, but it plummeted to 43.5% in 2000 and then fell to 25.4% in 2014 and 24.7% in 2015. These two major coal producing regions are followed by the rest of Asia (16.7% of total production in 2015), non-OECD Europe and Eurasia (8.1%), Africa (3.5%) and non-OECD Americas (1.3%). Total production of coal in 2015 amounted to 7,709 Mt. According to IEA's provisional data, approximately 90% of the total global coal in 2015 is produced by ten countries with China running in the lead. According to IEA, the top ten coal producing countries in 2015 were: China 3527 Mt (45.8%), United States with 813 Mt (10.5%), India with 691 Mt (9%), Australia with 509 Mt (6.6%), Indonesia with 469 Mt (6.1%), Russia with 349 Mt (4.5%), South Africa with 252 Mt (3.3%), Germany with 185 Mt (2.4%), Poland with 136 Mt (1.8%) and Kazakhstan with 107 Mt (1.4%) (IEA, 2016).

As stated by IEA, top ten coal exporters worldwide in 2014 were Australia (392 Mt), Indonesia (365 Mt), Russia (129 Mt), Colombia (82 Mt), South Africa (76 Mt), United

States (57 Mt), Kazakhstan (27 Mt), Canada (23 Mt), Korea (19 Mt) and Mongolia (14 Mt) (IEA, 2016).

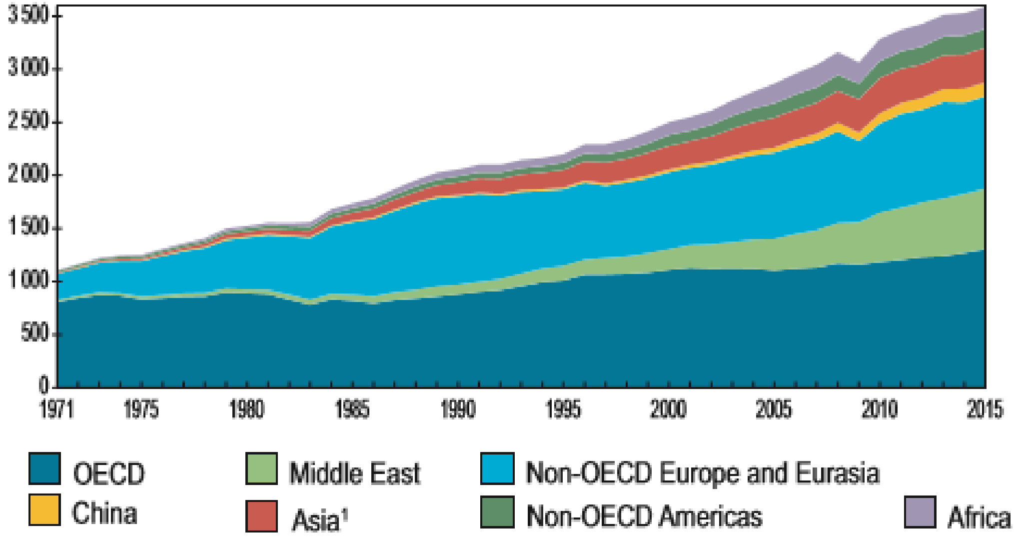
Natural Gas

According to IEA, natural gas is gaining increasing prominence in the global economy (IEA, 2015).

Natural gas extraction process is very expensive and costs a great deal of money to exploration and production companies to search and drill for natural gas. A team of geologists and geophysicists define where a natural gas deposit may be located and a team of drilling experts digs down the ground. Of course, there is always the risk that calculations were wrong and no natural gas will be found. Sometimes the quantity of natural gas present in a reservoir is too small and no extraction process takes place because it does not cover costs.

Proved reserves of natural gas are taken to be “those quantities that geological and engineering information indicates with reasonable certainty can be recovered in the future from known deposits under existing economic and operating conditions” (IEA). According to BP, global proved natural gas reserves fell slightly from 2014 to 2015, from 187 to 186.9 trillions of cubic meters (tcm), a decline of 0.1%. This decrease in gas reserves is driven by small decline in Russia. The majority of proved reserves are located in Middle East Region (42.8% of the global total) (BP, 2016). IEA has calculated that reserves are sufficient to meet 52.8 years if production were to continue at the current production rate (IEA, 2016). According to BP, countries endowed with more natural gas reserves in 2015 were in Iran (18.2% of global total), Russia (17.3%), Qatar (13.1%), Turkmenistan (9.4%), US (5.6%), Saudi Arabia (4.5%), United Arab Emirates (3.3%), Venezuela (3%), Nigeria (2.7%), Algeria (2.4%), Iraq (2%) and Australia (1.9%) (BP, 2016).

Figure 1.5: Natural gas production from 1971 to 2015 by region (billion cubic meters, bcm).



Source: Key World Energy Statistics 2016, IEA.

According to IEA, world total natural gas production amounted to 3,590 bcm in 2015. OECD countries represented the major producers of natural gas worldwide, accounting to 36.4% of total natural gas production. Other producers of natural gas were non-OECD Europe and Eurasia with 24.2% of total natural gas production, the Middle East with 16%, Asia (except China) with 9%, Africa with 5.8%, non-OECD Americas with 4.9% and China with 3.7% (EIA, 2016). According to IEA's provisional data, in 2015 more than 67% of world natural gas production came from the top ten countries: United States with 769 bcm (21.4% of the global total), Russia with 638 bcm (17.8%), Iran with 184 bcm (5.1%), Qatar with 164 bcm (4.6%), Canada with 164 bcm (4.6%), China with 134 bcm (3.7%), Norway with 122 bcm (3.4%), Saudi Arabia with 87 bcm (2.4%), Turkmenistan with 83 bcm (2.3%) and Algeria with 82 bcm (2.3%) (IEA, 2016).

According to IEA's provisional data, the top ten natural gas exporters in 2015 were Russia (192 bcm), Qatar (115 bcm), Norway (115 bcm), Canada (59 bcm), Turkmenistan (51 bcm), Algeria (44 bcm), Indonesia (33 bcm), Australia (28 bcm), Malaysia (25 bcm) and Nigeria (25 bcm) (IEA, 2016).

Nuclear

Nuclear technology was firstly developed in the 1940s for military purposes and then adapted for power generation. This technology uses the energy released by splitting the atoms of particular isotopes of uranium or plutonium. Nowadays, 11.5% of global electricity derive from nuclear power reactors (IEA, 2015). According to IEA, 447 reactors are located in 31 countries, and other 60 reactors are under construction, and through transmission grids, many other countries depend on nuclear-generated power. According to IEA, total world net installed capacity in 2014 was 384 GW. United States were leading the rank with 99 GW. Followed by France (63GW), Japan (42 GW), Russia (25 GW), China (24 GW), Korea (21 GW), Germany (14 GW), Canada (14 GW), Ukraine (13 GW), Sweden (9 GW), and the remaining 60 GW belonged to the rest of the world (IEA, 2016). According to BP, global nuclear output grew by 1.3% in 2015. China showed an increase of 28.9% with respect to the year before, Russia of 8%, and South Korea of 5.3%. Sweden and Belgium decreased their output respectively by 12.6% and 22.6%. France is abundantly the country that relies most on nuclear energy for electricity; in fact, it gets three-quarters of its power from it in 2014. France got 78.4% of nuclear in total domestic electricity generation, Ukraine 48.6%. Sweden 42.3%, Korea 28.7%, US 19.2%, UK 19%, Russia 17%, Canada 16%, Germany 15.6%, China 23% and the rest of the world 2.3% (IEA, 2016).

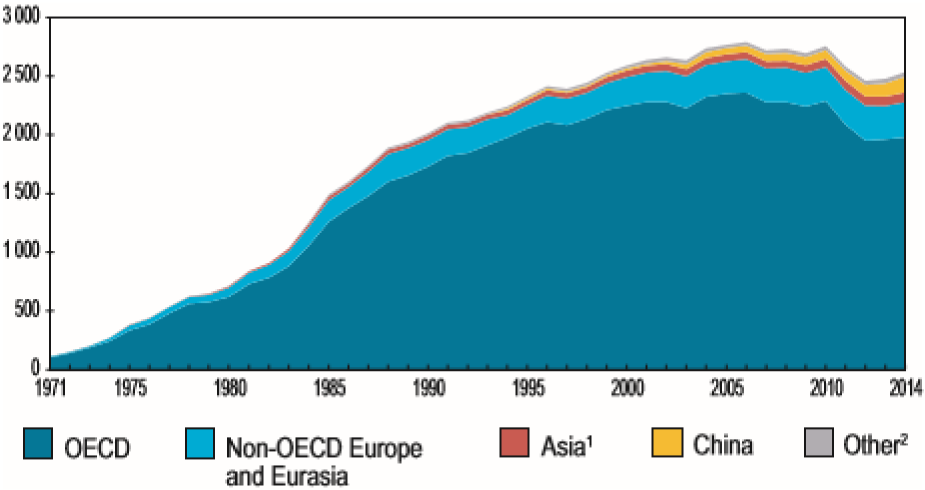
Nuclear energy is one of the most controversial energy sources. Positive aspects of nuclear power include that it:

- Reduces dependence on fossil fuels (oil and coal) and lowers greenhouse emissions. It benefits the situation of global warming and climate change even if pollutes the water used to cool the nuclear fission chambers;
- Needs less inputs (uranium) to produce the same amount of energy as coal or oil. Moreover, uranium is cheaper. Anyway, not every country is endowed with huge quantities of uranium, so some nations have to rely on others to get the amount they need for energy generation;
- The production of electricity is continuous, reliable and low-cost;
- Does not depend on natural aspects, as most renewable energies.

Despite these positive aspects, there exist an important downside related to nuclear power.

- Even if high sophisticated advances were made to safety systems of nuclear power plants, a little malfunction or wrong decisions during the management of the plant can cause catastrophic nuclear explosions or harmful radiation leaks;
- After nuclear explosion, radioactivity and risk for human health and environment take many years to be eliminated. Moreover, also small radiation emissions can have strong consequences on the surrounding area;
- Nuclear plants have an expiration date for security reasons. When the activity period is over, the plant must be dismantled and nuclear waste managed. Their construction is expensive and costs must be recovered during the lifetime of the plant.

Figure 1.6: Nuclear production from 1971 to 2014 by region (TWh).



Source: Key World Energy Statistics 2016, IEA.

As shown in figure 1.6, OECD countries have always been the major producers of nuclear energy, accounting for 78.1% of global production in 2014, followed by non-OECD Europe and Eurasia (11.8%), China (5.2%), the rest of Asia (3.3%) and Africa, non-OECD-Americas and the Middle East together (1.6%) (IEA, 2016). According to IEA, total nuclear production in 2014 was 2,535 TWh. Top ten nuclear generating countries in 2014 were United States with 831 TWh (32.8%), France with 436 TWh (17.2%), Russia with 181 TWh (7.1%), Korea with 156 TWh (6.2%), China with 133 TWh (5.2%), Canada with 108 TWh (4.3%), Germany with 97 TWh (3.8%), Ukraine 88 TWh (3.5%), Sweden with 65 TWh (2.6%) and United Kingdom with 64 TWh (2.5%) (IEA, 2016).

Renewable energy

Renewable energy is energy that can be obtained from natural resources. It takes advantage of the strength of nature or uses biomass to provide humanity with energy. This kind of energy will not run out of stock or can be produced and replaced in a short period. Renewables include hydro, solar, wind, geothermal and bio energy.

Despite renewable energy and green energy are often used as synonymous, there exist a difference between them. Renewable energy will not run out any time soon, as hydro, wind, solar energy and biofuels. Green energy is that type of energy that is good for the environment because does not harm ecosystems or worse global warming, like, for example, solar energy. Not all types of renewable energy are also green. On the other hand, all green energy is renewable. For example, biofuels are renewable but not green, because they emit several harmful gases.

In the paragraphs below, all different types of renewable energies are explained in detail.

Hydro

Energy created by flowing water (called hydropower) can be captured and transformed into electricity. One common type of hydroelectric power plants is called “reservoir” hydropower plant and uses a dam to store water. It generate power by releasing water through a turbine, which is connected to a generator that in turn produces electricity. The “run-of-power” hydropower plant simply uses a canal to channel the water instead of a large dam. This type of plant can have short-term storage, allowing for hourly or daily flexibility. Another common type of plant is called “pumped storage plant”, and it is able to store water and then, energy. To generate electricity, generators spin the turbines backward from the lower reservoir to the upper one. The release of water spins the turbines forward and activates the generators to produce electricity and meet the excess electricity demand.

Large hydropower plants can generate more than 30 MW. A small or micro hydroelectric power system can produce enough electricity for a home. Small hydropower plants generate 10 MW or less of power, while micro plants have a capacity of up 100 kilowatts.

Benefits from hydropower technology are several:

- Constructing a dam is a long-term investment, because dams are designed to last many decades;
- Electricity can be produced at a constant rate, once the dam is constructed. This makes hydroelectricity a reliable energy;
- Adjusting water flow and output of electricity is easy and can be adapted to demand. When demand Is low, water can be saved in a reservoir and conserved in order to manage supply also in periods of high demand;
- The water stored can be used in many ways, such as leisure (for example for water sports) or irrigation purposes;
- Hydropower energy is green and renewable, it does not produce any green house gases and cannot be used up.

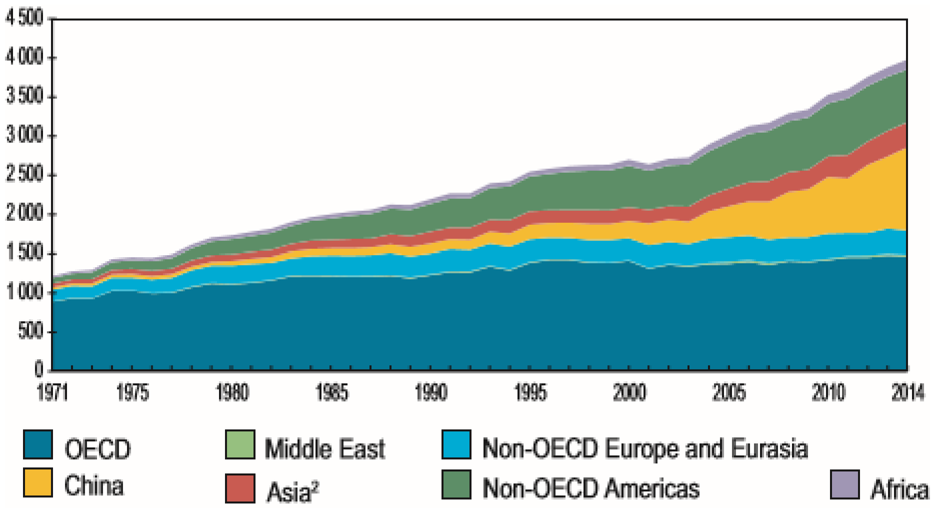
Although this kind of energy carry many advantages with it, there are some downsides related to it:

- Dams are extremely expensive to build and take a lot of time to be finished because they must accomplish to rigid high standards. Therefore, many decades are needed to recover the investment and be productive. Anyway, maintenance costs are generally low;
- Dams need a lot of space to be constructed. The flooding of large areas forces many people to move out, and destroys the natural environment, also causing serious geological-biological damages and altering the natural water table level;
- Blocking the natural progress of a river means changing the water supply from the same river to the following country. This can create problems between neighbor countries;
- In very extreme cases, old and bad constructed dams can led to deaths and flooding.

Hydropower is a mature and cost-effective renewable energy source. Nowadays, it contributes to around 2.2% of worldwide power generation and represents the more utilized renewable source (IEA, 2016). According to IEA, China had the largest share of hydropower capacity installations in 2014, amounting to 311 GW of net installed capacity. Other countries endowed with several hydropower installations are US (102

GW), Brazil (89 GW), Canada (76 GW), Russia (51 GW), Japan (50 GW), India (40 GW), Norway (31 GW), France (25 GW) and Turkey (24 GW). The rest of the world accounts for 372 GW net capacity installations, amounting for a global total of 1,171 GW (IEA, 2016). The biggest hydropower plants worldwide are in China. The hydropower plant with highest installed capacity (22,500 MW) is located in China and is called Three Gorges Dam. The second plant with high installed capacity is in Brazil/Paraguay and is called Itaipu Dam. Despite the Itaipu Dam has 14,000 MW of installed capacity, Three Gorges Dam and Itaipu Dam have an equal annual production of almost 99 TWh. Other massive plants are located in United States, Russia and Canada.

Figure 1.7: Hydro production from 1971 to 2014 by region (TWh).



Source: Key World Energy Statistics 2016, IEA.

Figure 1.7 shows worldwide hydropower production from 1971 to 2014. According to IEA, The highest share of hydropower production is generated in OECD countries (36.8% of global total), followed by China (26.7%), non-OECD Americas (17%), the rest of Asia (8%), non-OECD Europe and Eurasia (7.8%), Africa (3.2%) and Middle East (0.5%). Total hydropower production in 2014 was 3983 TWh (IEA, 2016). According to IEA, China lead the world in hydropower production in 2014, totaling 1,064 TWh (26.7% of world total). Other top hydropower producers in 2014 were Canada with 383 TWh (9.6% of world total), Brazil with 373 TWh (9.4%), United States with 282 TWh (7.1%), Russia with 177 TWh (4.4%), Norway with 137 TWh (3.4%), India with 132 TWh (3.3%), Venezuela with 87 TWh (2.2%), Japan with 87 TWh (2.2%) and France with 69 TWh (1.7%). The rest of the world amounted to the remaining 1192 TWh (30%) (IEA, 2016). Countries that more relied on hydropower in total domestic electricity generation in 2014 were Norway (96%), Venezuela (68.3%), Brazil (63.2%), Canada (58.3%), China (18.7%), Russia (16.7%), France (12.2%), India (10.2%), Japan (8.4%) and US (6.5%) (IEA, 2016).

Solar

Photovoltaic systems are becoming increasingly popular nowadays, due to rising cost-efficient installations and government support (REN21, 2016). According to REN21, 2015 has been another year of record for new capacity installations, increasing solar capacity up 25% over 2014 (REN21, 2016).

Solar cells are made of modified silicon or other semi-conductive materials that capture sunrays and convert them into clean electricity. Photovoltaic panels are usually placed on a roof and wired to a building through an inverter. The inverter converts the energy generated by the solar cell (direct current-DC) into alternating current (AC).

There are three basic types of PV technologies: monocrystalline, polycrystalline and thin-film. Usually, the one that works best in terms of efficiency is the monocrystalline; the cheaper is the thin-film instead, and its efficiency is improving thanks to the recent high demand for PV systems.

Advantages of photovoltaics panels are several; they:

- Exist in many designs and sizes and are easy to accommodate and be oriented on most roofs; moreover, the power ratings can easily be upgraded just by adding more panels;
- Are reliable: likely to work at least 20 years and restorations are easy and cheap to be made;
- Are quiet;
- Decrease the owner’s dependence from the energy grid, lowering bills and future electricity cost;
- Can benefit from some economic facilities in many countries;
- Are “green”: they do not pollute, no chemical components are released.

On the other hand, they:

- Need a big initial investment, even if it can be amortized during the lifespan of the panels. Moreover, photovoltaic systems are cheaper nowadays compared to about 10 years ago (they cost almost one third);
- Provide non-homogeneous electricity depending on the availability of sun light and alternation of day and night, and energy cannot be stored.

Many countries have installed new solar power capacity to provide an alternative to conventional energy sources and reduce their dependence on expensive imported energy sources. According to REN21, in 2014, overall installed capacity increased by 40 GW (28%). By the end of 2014, cumulative photovoltaic capacity reached more than 178 GW, sufficient to supply 1 percent of global electricity demand. In terms of cumulative capacity, Europe was still the leading country with 88 GW of installed capacity (18% of the global total), but new installed capacity (7 GW) declined for the third consecutive year compared to the record year 2011, when 22 GW were installed. In 2015, global capacity has reached about 226 GW, 48 GW more with respect to the year before, corresponding to about 185 million solar panels added. China accounted for 30% of total global additions (15.2 GW) in 2015. In the rank of top solar new capacity installers, there were Japan with 11 GW added (22% of total), that in only three years has doubled its renewable energy capacity, North America (7.9 GW added, of which 7.3 GW in United States, representing the 15%), Europe (7.5 GW added), India (2 GW added) and Korea (1 GW added). Europe market picked up after three years of decline, accounting for almost 95 GW of operating installed capacity, the highest worldwide. At the end of 2015, Europe had enough PV installed capacity to meet 3.5% of total consumption (REN21, 2016). According to REN21, other leading countries for total installed capacity in 2015 were China, with around 45 GW of installed capacity, Germany, the previous top country for solar PV installations, overcome by China in 2015, with 40 GW, Japan (around 35 GW), United States (almost 30 GW), Italy (20 GW), United Kingdom (10 GW), and France, Spain, India and Australia with less than 10 GW of installed capacity (REN21, 2016).

In 2015, solar PV played an important role in electricity generation in several countries. In Italy it met 7.8% of electricity demand, 6.5% in Greece and 6.4% in Germany (REN21, 2016).

Wind

Wind power constituted the leading source of renewable power generating capacity in 2015, in both Europe and United States and placed second in China. Wind is estimated to have supplied more new power generation worldwide than any other technology in 2015, and new installations have reached a new record (REN21, 2016).

Wind turbines are used to generate electricity or mechanical power from wind. Wind flows simply turn the blades, which are connected to a generator that makes electricity or purely transform the kinetic energy into mechanical power.

There are two basic types of wind turbine: the horizontal one, which typically has two or three blades operating "upwind", and the vertical one. Wind turbines can have different sizes and power ratings, from 100 kilowatts to several megawatts. The larger the turbines, the most cost effective they result. Big ones are usually located into wind farms and connected to a power grid in order to bulk and supply electricity to customers. They range in size from 50 kilowatts to 750 kilowatts. Single small turbines are used for homes or water pumping instead, and they are usually below 50 kilowatts.

Wind turbines benefits:

- They produce clean and non-polluting electricity; wind plants do not emit greenhouse gases or any pollutants;
- Even if the initial investment for wind technology is higher than fossil-fueled generators, they result far more convenient on a life cycle cost basis;
- They are able to store wind-generated energy if batteries are used.

Among disadvantages:

- Wind flows and patterns vary greatly across countries. Wind is intermittent and not always blows when electricity is needed;
- Wind turbines are noisy;
- Are bulky and use land that can be used in other ways;
- Have a great aesthetic impact on the surroundings and can cause problems to birds and bats.

According to REN21, worldwide cumulative wind capacity increased by 17% in 2015 with respect to the year before, totaling 433 GW. China amounted for more than one third of the global installed capacity and had by far the world's biggest wind power sector. In 2015, China totaled 145.36 GW (34.1%) of total installed capacity, followed distantly by

United States 74.47 GW (17.5%), Germany 44.94 GW (10.5%), India 27.15 GW (6.4%), Spain 23.02 GW (5.4%), United Kingdom 13.60 GW (3.2%), Canada 11.20 GW (2.6%), France 10.35 GW (2.4%), Italy 8.95 GW (2.1%) and Brazil 8.71 GW (2.0%). In 2015, new wind power installations amounted to 63 GW in total, 12 GW more than the ones installed in 2014. China lead the rank of the top new capacity additions in 2015, with 30.75 GW added (48.5% of the global total), followed by The United States with 8.60 GW (13.5%), Germany with 6.1 GW (9.5%), Brazil with 2.75 GW (4.3%), India with 2.75 GW (4.3%), Canada with 1.50 GW (2.4%), Poland with 1.26 GW (2.0%), France with 1.07 GW (1.07%), United Kingdom with 975 MW (1.5%) and Turkey with 956 MW (1.5%) (REN21, 2016).

Geothermal

Geothermal energy is obtained from the heat from the Earth. Its resources range from the shallow ground to hot water and hot rock, well beneath the Earth's surface. Geothermal system is able to provide energy in form of electricity and to heat and cool buildings exploiting some very hot places inside the earth, called hot spots. That particular technology consists of a heat pump, an air delivery system and a system of pipes buried near the building, called heat exchanger. During the winter, the heat exchanger removes the heat from the ground and pump it indoor through the air delivery system. The reverse occurs in summer: the heat pump removes heat from the indoor and pump it into the heat exchanger that is able to use the heat to provide hot water.

Some geothermal plants use underground water reservoirs to generate electricity. They use the steam from the reservoir to activate a generator or hot water to boil a fluid that vaporizes and turns a turbine.

Other plants use hot rock resources to provide electricity. Cold water is injected down one well and it reaches hot rocks which are usually 3 or 5 miles beneath the surface, then the heated water is drawn off from another well. Unfortunately, there is no commercial application for this type of technology yet. Moreover, nowadays recovery of heat from magma is not possible with available technology.

The energy production potential of this source is low.

Geothermal energy:

- Can be used directly, without wastage or generation of by-products;
- Does not depend on weather conditions as solar energy does. In facts, geothermal energy is one of the rare types of renewable energy not directly or indirectly related to solar energy;
- Is clean, sustainable and renewable;
- Geothermal power plants do not occupy much space, because the majority of the technology is underground.

Despite advantages listed before, downsides are several:

- Even if maintenance costs are cheap, Installation costs are very high;
- Construction of geothermal energy plants can cause seismic disturbances and lead to earthquakes. Moreover, some potential harmful and poisonous gases may be released during the installation;
- Most of the rich-geothermal energy areas are far away from cities where electricity is needed;
- Not all the sites have the potential for geothermal energy production. There is no guarantee that the capital expenditure will be recovered through the energy produced. In general, the generation potential of this source is small;
- Is not reliable because geothermal sites can run out of stream due to drop in temperature;
- Cannot be transported. Geothermal energy can serve only surrounding areas.

According to REN21, around 315 MW of new geothermal generating capacity was added in 2015, reaching a total of 13.2 GW worldwide. Capacity additions were lower with respect to years before. Turkey represented almost 50% of the new added capacity, with more 159 MW completed in 2015. United States added 71 MW (22%), Mexico 53 MW (17%), Kenya 20 MW (6%), and Germany and Japan with around 5.5 MW (2%). Top countries with highest geothermal generating capacity in 2015 were United States (3.6 GW), Philippines (1.9 GW), Indonesia (1.4 GW), Mexico (1.1 GW), New Zealand (1.0

GW), Italy (0.9 GW), Iceland (0.7 GW), Turkey (0.6 GW), Kenya (0.6 GW) and Japan (0.5 GW) (REN21, 2016).

Bioenergy

Bioenergy is energy directly or indirectly derived from biomass, organic material such as plant materials, animal waste, agricultural crops, forestry, agro industry and food industry. Bioenergy can be directly or indirectly produced from biomass, it means that it can be made by or from biomass, because it can be derived by dead material that was once living or created through chemical reactions carried out in a laboratory, where organic matter is used. Raw materials can be converted and used for heat and cooling, electricity and biofuels. This flexibility is unique between all the renewable energy sources.

The most common way to produce bioenergy is through the combustion of biofuels. The real important requirement for the production of biofuel is that the starting material must be hydrocarbon (CO_2), but it does not matter if it is produced in laboratory or through chemical reactions. Using hydrocarbon, biofuels can be produced in a short period of time, days or months, since biomass is renewable and can be produced easily and quickly. This constitute one of the greater advantage that biofuels have over fossil fuels, which need millions of years to form.

There exist a distinction between primary and secondary generation of biofuels. Primary biofuels, such as pellets, are used in an unprocessed form, for heating, cooking or producing electricity. Primary generation biofuels use only a portion of the energy potentially available in the biomass. Secondary biofuels result from processing biomass instead, and include liquid biofuels such as ethanol and biodiesel.

According to REN21, greater enthusiasm for biofuels started recently, and governments looking for energy security, promoted biofuels with tax incentives and import restrictions. Anyway, large-scale production of biofuels from crops require large land areas to grow them, and increases competition for natural resources, especially land and water. This will affect the food security of developing and underdeveloped countries since richer countries will be able to buy or lease land for both food and energy production, while poorer ones will not have land for their own food subsistence. Second generation biofuels can decrease the competition for land since they are able to use more crop potential for the production of energy, compared to first generation biofuels (REN21, 2016).

In the table below are listed some of the most popular and widely used biofuels available. The comparison between biofuels and fossil fuels is described in the right-hand column.

Table 1.1: Biofuels and fossil fuels comparison.

Biofuel	**Fossil Fuel**	**Differences**
Bioethanol	Gasoline	Bioethanol has about half the energy per mass compared to gasoline. It needs twice quantity of bioethanol to bring the same energy of gasoline. Bioethanol produces more ozone than gasoline but less carbon monoxide. Engines must be modified to run on bioethanol.
Biodiesel	Diesel	Biodiesel has quite the same energy per mass than diesel. Engines must be designed to run on biodiesel because it is more corrosive than regular diesel. It burns cleaner than diesel.
Methanol	Methane	Methanol has less than half the energy per mass than methane, but it is cleaner and easier to transport since it is liquid. Methane must be compressed for transportation because is a gas.
Bio-butanol	Gasoline/Butanol	Bio-butanol has quite the same energy than gasoline, but it is cleaner and does not need any modification of the engine if it already runs on gasoline.

Source: Author's elaboration.

Gasoline, diesel, methane and butanol are non-renewable fuels primarily used for engines. Gasoline is a transparent liquid derived from petroleum, from which it obtain its organic compounds. Diesel is a liquid fuel used to ignite diesel engines, which are quite different from gasoline engines. Methane (or natural gas) is a natural hydrocarbon gas composed mostly by methane and in smaller percentages by nitrogen, hydrogen sulfide or helium. Finally, butanol is a four-carbon alcohol similar to gasoline.

The quantity of these fuels is limited and their use contribute to greenhouse emissions and pollution. For these reasons, other less polluting and more environmental friendly substitutes have been investigated in the attempt to move from a fossil fuel-based economy to a more sustainable one. Anyway, renewable energy fuels such as bioethanol, biodiesel, methanol and bio-butanol still have some limitations compared to traditional fuels. As described in table 1.1, some of them need special engine or engine modification to work, and more quantities of them are required compared to traditional fuels to give the same amount of energy. However, they are renewable and cleaner with respect to fossil fuels. Biofuels are not green because they emit harmful gases but not as much as fossil fuels, so pollution can be limited through an intensive use of biofuels.

Bioethanol is often used as a biofuel additive to gasoline, even if nowadays cars are able to run entirely on ethanol. It is made from crops such as hemp, sugarcane, potato and corn but, according to REN21, ethanol fuel produced from cellulose may allow it to play a much bigger role in the future. In fact, cellulosic ethanol may decrease its dependence on food prices and on the large amount of land needed for crops (REN21, 2016). The cost of producing bioethanol remains higher than the one of producing fuels from petroleum. Anyway, research and development are investigating in new production technologies able to cut costs.

Bio-butanol refers to butanol obtained from biomass, is a second generation alcoholic biofuel produced from the fermentation of sugars, starch and other biomass or through pyrolysis and reformulation of biomass. Biobutanol is not available yet on large commercial scale because its production is currently expensive, but it has several advantages over ethanol: it has higher energy density and a high potential for competing with oil, it can be used in existing vehicles without any need of modification because it is less corrosive and it can be blended with gasoline in higher percentage. Moreover, it potentially has little or no impact on food supply. It is currently the focus of massive research and development.

Methanol is an alcohol fuel that can be used directly as biofuel, as additive to gasoline or as diesel replacement. It can be produced using various feedstocks but natural gas is the most used and economical. Methanol is desirable because it burns cleaner and is cheaper with respect to other fuels and is easy to transport, but it needs engine modifications because it is corrosive to certain materials.

Biodiesel is a biofuel derived from vegetable oil or animal fats that can be used directly or blended with petroleum-based diesel fuel. It can be used in existing diesel engines without modifications. Alt Although the process to create biodiesel is quite simple, homemade biodiesel is not recommended because it must comply with some industry requirement to avoid engine damage, loss of warranty or operational problems. EPA has classified it as an Advanced Biofuel because its environmental benefits. In fact, according to EPA, biodiesel reduces greenhouse gas emissions by at least 57%.

Advantages of biofuels:

- Are easy to source since they are made by waste from crops and plants. They represent also a step forward in recycling, making possible to use waste that should be otherwise be cleared out;
- Are renewable;
- Are cleaner compared to fossil fuel, they produce fewer emissions and even if they are not totally green. They produce greenhouse gases despite not as much as fossil fuel;
- Most of them are adaptable to current engines;
- Even if nowadays they are not cheaper than fossil fuel, they carry much higher cost benefits for the environment. Moreover, they have the potential to be cheaper in the future;
- Reduce dependence on foreign oil and provide economic security. In fact, biofuels can be produced locally.

Disadvantages:

- Even if they are renewable, the quantity of biofuels that can be produced is not limitless. In fact, biofuel production needs large land areas to grown biomass and this process steal land from growing food. As the population grows, both food and energy demand increase. This will result in land utilization conflicts; land can be utilized to produce either food or energy. When the space will not be sufficient to meet both needs the price of both food and energy will boost. Increase in food price would not be a big issue for wealthier countries, but it can have tremendous impacts on poorer nations. Land grabbing phenomenon can arise in underdeveloped and developing countries;

- Production of biofuels is expensive and large scale industries emit large amounts of emissions, making up with emissions saved by biofuel consumption. Anyway, more efficient practices of production are currently under development;
- Biofuels production have negative consequences on biodiversity. In order to produce biofuels, the easiest crop to be grown (that is the one that requires little amount of water and other resources) is selected and cultivated year after year. Monoculture deprives the land of nutrients that are put back in the soil by crop rotation, yielding the land infertile. Moreover, pests that eat that kind of crop proliferate, becoming stronger and stronger and even resistant to pesticides;
- Pesticides used to protect crops from pests damage the environment and also cause water pollution;
- Production of biofuels cause water pollution and need large quantities of water to irrigate biofuel crops. Water grabbing phenomenon can arise in underdeveloped and developing countries.

According to REN21, “in 2015, drivers for the production and use of biomass energy included rapidly rising energy demand in many countries and local and global environmental concerns and goals. Challenges to bioenergy deployment included low fossil fuel prices and rapidly falling energy prices of some other renewable energy sources, especially wind and solar PV. Ongoing debate about the sustainability of bioenergy, including indirect land-use change and carbon balance, also affected development in the sector. Given these challenges, national policy frameworks continue to have a large influence on deployment” (REN21, p.43, 2016).

Since 2010, the use of biomass for energy at global level has been growing at around 2% per year (REN21, 2016). Modern heat capacity from biomass increased by $10GW_{th}$, for a total of 315 GW_{th}. According to REN21, leading countries relying on biomass for industrial heat in 2015 were Asia and South America (particularly Brazil), followed by North America. In the buildings sector, the major consumers of biomass were United States, Germany, France, Sweden, Italy and Finland. Indeed, Europe was the largest market for buildings sector, but also for wood pellets for heating, especially Italy, Germany, Sweden and France. As regard the transport sector, total biofuel production increased by 3% compared to the year before, totaling 133 billion liters (REN21, 2016).

According to REN21, bio-power generation increased by 8% in 2015, following a better use of existing capacity and 5% capacity additions. Leading countries in electricity generation were United States (69 TWh), Germany (50 TWh), China (48 TWh), Brazil (40 TWh) and Japan (36 TWh) (REN21, 2016).

According to REN21, in 2015 total production of biofuels increased by 3% compared to 2014, reaching 133 billion liters. The scene was dominated by United States and Brazil, which together accounted for 72% of total biofuels production. Around 67% of biofuel production in energy terms came from fuel ethanol, 33% from biodiesel. Global production of fuel ethanol in 2015 increased by 4% from the year before, to 98.3 billion liters, mostly determined by US production, which rose by 3.8% (56.1 billion liters). China and Europe ethanol production was down by about 14% and 7% respectively. According to REN21, largest ethanol producers in 2015 were United States, Brazil, China, Canada and Thailand.

Biodiesel production fell slightly from 2014, from 30.4 billion liters to 30.1. Biodiesel production in US rose by 2% to 4.8 billion liters and in Brazil up 20% to 4.1 billion liters with respect to 2014. European biodiesel production increased by 5% to 11.5 billion liters, with Germany as European leading country. According to REN21, the leading countries in biodiesel production were United States, Brazil, Germany and Argentina.

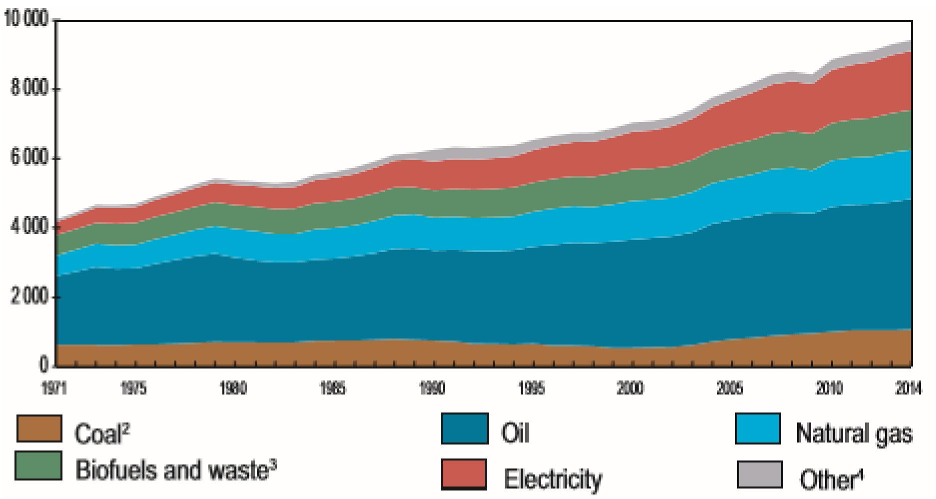
According to REN21, bioenergy share in total global primary energy consumption has remained relatively steady at 10% since 2005, despite a 24% increase in overall global energy demand between 2005 and 2015. Bioenergy accounts for around 10% of all industrial heat consumption, and its use in industry has been growing at about 1.3% per year over the past 15 years (REN21, 2016).

In the end, total energy production continued to increase during 2014, but at a slower rate compared to years before. In fact, total increase in energy production in 2014 was 0.8% with respect to 2013, showing the lowest recorded growth since 1999, except for the 2009 recession. Oil production decreased but still represented the major source of energy worldwide. On the contrary, clean and renewable production of energy boosted. Capacity and production from renewables increased in the attempt to fight environmental issues and to decrease dependence from fossil fuels and fossil fuels producing countries.

1.2. Energy consumption

According to REN21, world energy consumption is the total energy used by humanity in order to meet its needs. The desire for energy is changed in recent years; countries have risen their needs and are consuming increasing quantities of energy. Moreover, energy access is improving even in developing nations, enabling countries that had not access to energy before to get it and improve their living standards. Anyway, resources are consumed at an unsustainable level (REN21, 2016). According to a research made by World Economic Forum, the seven billion people on Earth consume different amounts of resources depending on the country in which they live. If everyone on Earth would consume resources at the same rate as Russia and South Korea, 3.3 Earths would be needed to sustain that consumption, 4.8 Earths for United States and 5.4 Earths for Australia. This figure is going to increase due to expected rising worldwide population (World Economic Forum, 2016).

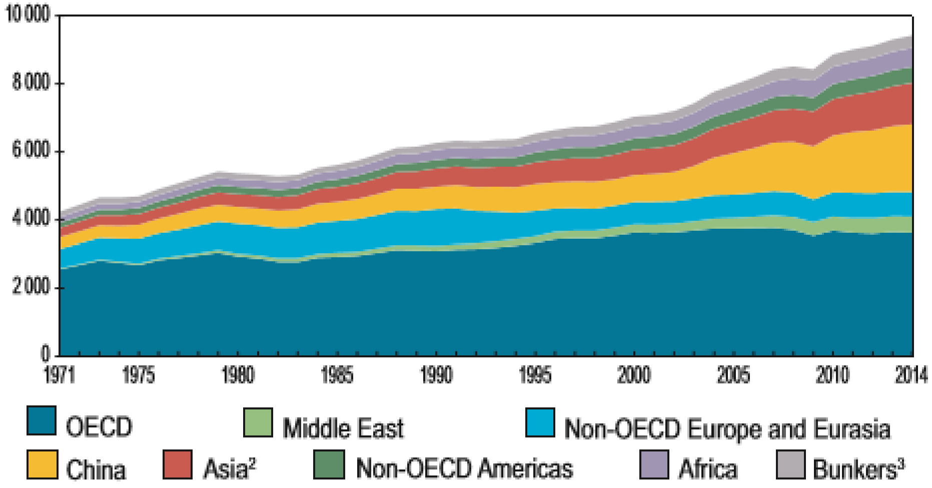
Figure 1.8: World total final consumption from 1971 to 2014 by fuel (Mtoe)



Source: Key World Energy Statistics 2016, IEA.

According to IEA, in 2014 total energy consumption worldwide was 9,425 Mtoe. Oil represented 39.9% of total energy consumption, electricity 18.1%, natural gas 15.1%, biofuels and waste 12.2%, coal 11.4% and geothermal, solar and wind the remaining 3.3% (IEA, 2016).

Figure 1.9: World total final consumption from 1973 to 2014 by region (Mtoe).



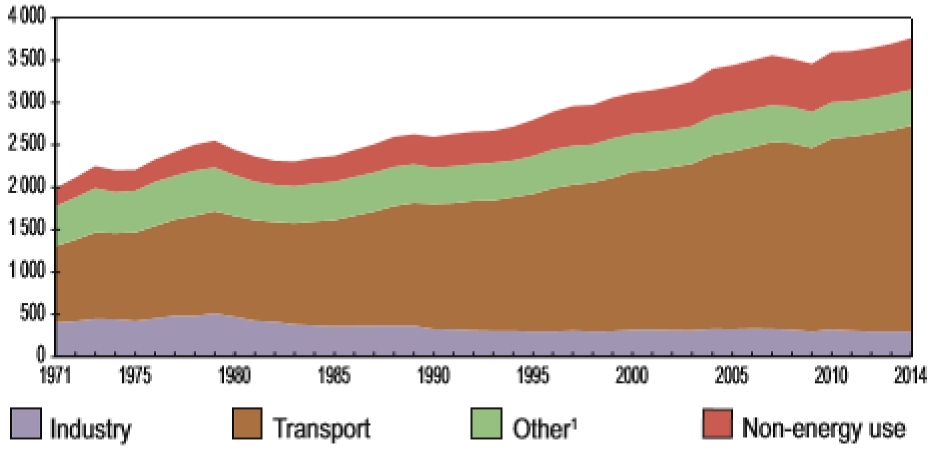
Source: Key World Energy Statistics 2016, IEA.

According to IEA, total consumption almost doubled from 1973 to 2014, from 4,661 Mtoe to 9,425 Mtoe. OECD countries still accounted for the highest share of energy consumption in 2015, with 38.4% or 3,629 Mtoe of global total. More specifically, OECD Americas accounted for 51.8% of OECD countries total consumption, OECD Europe for 32.3% and OECD Asia Oceania for 15.9%. OECD countries' total final consumption by fuel in 2015 is constituted by 47.2% of oil, 22.1% by electricity, 20.3% of natural gas, 5.5% of biofuels and waste, 3.1% of coal and 1.8% of geothermal, solar and wind. Other top consuming countries in 2014 are China, with 21.2% of total global energy consumption, the rest of Asia with 12.9%, non-OECD Europe and Eurasia with 7.6%, Africa with 5.9%, Middle East with 5.1%, non-OECD Americas with 5% and Bunkers with 3.9% (IEA, 2016).

Crude oil

Average demand for crude oil has increased by 1.52% in the last 20 years, and from 2014 to 2015 there was an increase of 1.9%, or almost two million barrels per day (EIA, 2016). According to IEA, world energy consumption of oil reached 3,761 Mtoe in 2014. The top ten importers of oil in 2014 were United States (344 Mt), China (308 Mt), India (189 Mt), Japan (165 Mt), Korea (126 Mt), Germany (89 Mt), Spain (61 Mt), Italy (59 Mt), France (54 Mt) and Netherlands (54 Mt) (IEA, 2016). As shown in figure 1.10, the higher share of oil consumption has always been for transport purposes, reaching 64.5% in 2014, followed by non-energy use (16.2%), other (11.3%) and industry (8%) (IEA, 2016). Other includes agriculture, commercial and public services, residential and others (IEA, 2016).

Figure 1.10: Total final oil consumption from 1971 to 2014 by sector (Mtoe).



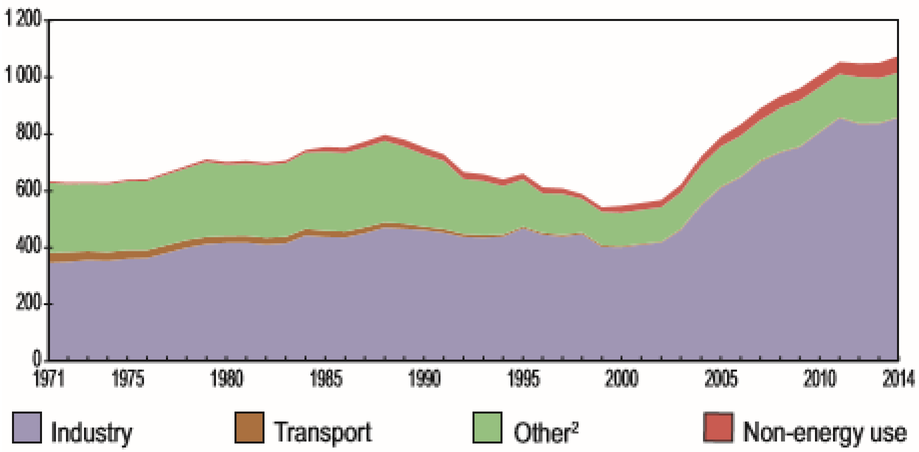
Source: Key World Energy Statistics 2016, IEA.

Coal

Global consumption of coal in energy terms decreased by 2.6% (148 Mtoe) in 2015 (IEA, 2016). This reduction was due to 6.3% decreased consumption in OECD countries and 4.1% decline in non-OECD countries (IEA, 2016).

According to IEA, total coal consumption in 2014 was 1,075 Mtoe, of which 79.8% was devoted to the industry sector, 14.4% to other sectors, 5.5% to non-energy use and 0.3% to transport sector (IEA, 2016). According to IEA, total coal imports hit a new record in 2014, reaching 1,409 Mt. For the first time, world coal imports decreased in 2015, a global decline of 6.0% from 2014 numbers. Top coal importers in 2014 were India with 221 Mt, China with 199 Mt, Japan with 192 Mt, Korea with 135 Mt, Chinese Taipei with 66 Mt, Germany with 54 Mt, Turkey with 34 Mt, United Kingdom with 25 Mt, Malaysia with 24 Mt and Thailand with 23 Mt. total imports amounted to 1,206 Mt (IEA, 2016).

Figure 1.11: Total final coal consumption from 1971 to 2014 by sector (Mtoe).



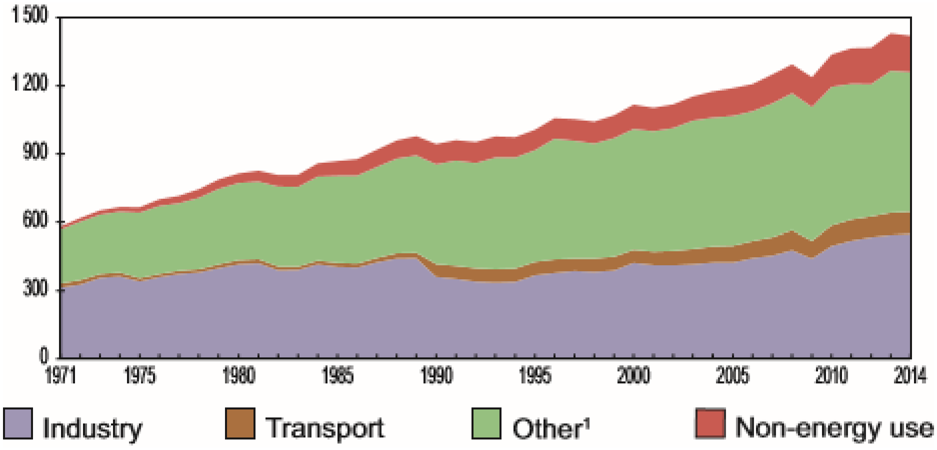
Source: Key World Energy Statistics 2016, IEA.

Natural Gas

In 2014, world natural gas energy consumption was 20.3% of global total consumption (IEA, 2016). According to IEA, 43.2% of total natural gas consumption was devoted to agriculture, commercial and public services, residential and other sectors, 38.6% to industry sector, 11.3% to non-energy use sector and 6.9% to transport sector. Transport sector is also growing, due to increasing private and public vehicles using that kind of fuel (IEA, 2016). According to IEA's provisional data, the top ten natural gas importers in 2015 were Japan with 117 bcm, Germany with 73 bcm, Italy with 61 bcm, China with

56 bcm, Turkey with 48 bcm, Korea with 43 bcm, France with 39 bcm, Mexico with 37 bcm, United Kingdom with 31 bcm and Spain with 27 bcm. Total imports accounted for 812 bcm (IEA, 2016).

Figure 1.12: Total natural gas final consumption from 1971 to 2014 by sector (Mtoe).



Source: Key World Energy Statistics 2016, IEA.

Renewables

Power sector experienced a significant growth in renewables capacity additions, especially due to wind, solar PV and hydropower. According to REN21, renewables capacity additions worldwide overcame capacity additions from all fossil fuels combined in 2015. At the end of 2015, total renewable capacity was able to satisfy an estimated 23.7% of global electricity, with hydropower providing 16.6% (REN21, 2016). Power from hydro, geothermal and some biomass has been broadly competitive with power from fossil fuels due to cost competitiveness and other cost improvements (REN21, 2016). According to REN21, renewable electricity production in 2015 has been highly dominated by large generators, even if small-scale generators spread and grid improvements were made to provide electricity for people living far from the grid.

Heating and cooling sector from renewables is dominated by biomass, with small contributions from solar thermal and geothermal energy. According to REN21, total generation and capacity of renewables in heating and cooling sector continued to rise in 2015, even though global growth rate declined, especially due to low oil prices. Policy support in this sector remained inadequate compared to other sectors, but signals of international awareness may be on the way (REN21, 2016).

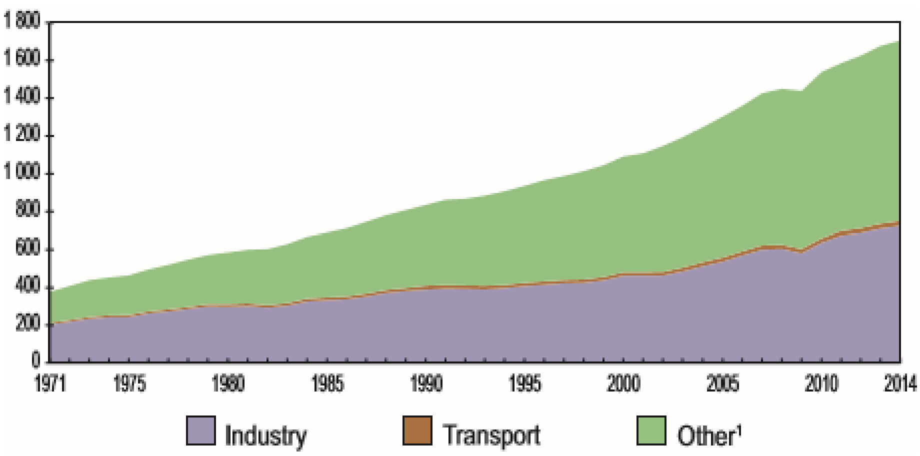
According to REN21, renewable energy accounted for about 4% of total fuel used in transport sector in 2015. New developments and contributions for the sector took place in 2015, such as aviation biofuels, new technologies and vehicles. Liquid biofuels constituted the major contribution of renewable energies for the transport sector. Policy support was still lower than that for the power sector (REN21, 2016).

In the end, as with production, also consumption of energy increased in the past few years. Since fossil fuel resources are limited and are detrimental for the environment, consumption of renewable resources increased, but the majority of the demand continued to be satisfied by fossil fuel-generated energy. Increasing populations demand increasing amount of energy to satisfy their additional needs and improved energy standards. Moreover, wider energy access even in more remote areas has permitted to a greater part of the population to take advantage from energy use.

Electricity

In 2014, total world electricity consumption amounted to 1,706 Mtoe, of which 56% devoted to agriculture, commercial and public services, residential and others, 42.5% to industry and 1.5% to transport.

Figure 1.13: Total final electricity consumption from 1971 to 2014 by sector (Mtoe).



Source: Key World Energy Statistics 2016, IEA.

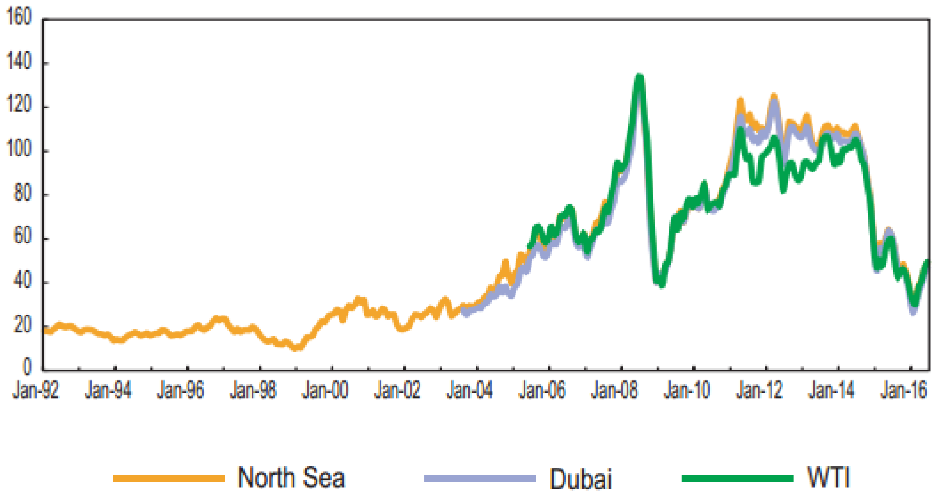
Energy Prices

Energy prices include oil, natural gas, coal and renewable energies prices. According to British Petroleum (BP, 2016), the price of energy depends on several factors, such as weather conditions, the level of public policies support, taxation and supply and demand conditions, which include the geopolitical situation, import diversification, network and environmental costs. The price and reliability of energy supplies are important for a country's energy supply strategy and energy security issues. Electricity prices are particularly important for households and businesses as it represent a key element in international competitiveness. In fact, electricity costs usually corresponds to a significant proportion of total energy costs for industrial and service-providing businesses. Electricity prices can vary widely between and within countries, due to factors such as infrastructure and geography (BP, 2016). According to BP, worldwide fossil fuel prices fell in 2015. Prices for crude oil recorded the largest percentage decline since 1986, natural gas prices decreased everywhere, especially in North America, and global coal prices declined for the fourth consecutive year (BP, 2016).

According to BP, Brent crude oil prices were $52.39 per barrel on average in 2015, that is $46.56 per barrel less with respect to 2014. Prices started to grow again at the beginning of 2015, but due to strong growth in OPEC production, they declined again later in the year. Because of the increasing imbalance between global production and consumption, the international crude oil benchmark Brent, saw its annual average price decline by 47% in 2015. Moreover, the Brent-West Texas Intermediate (WTI) differential narrowed to $3.68 for the third consecutive year, that is, its smallest level since 2010. At international trade level, Brent and WTI are the most used benchmarks (BP, 2016).

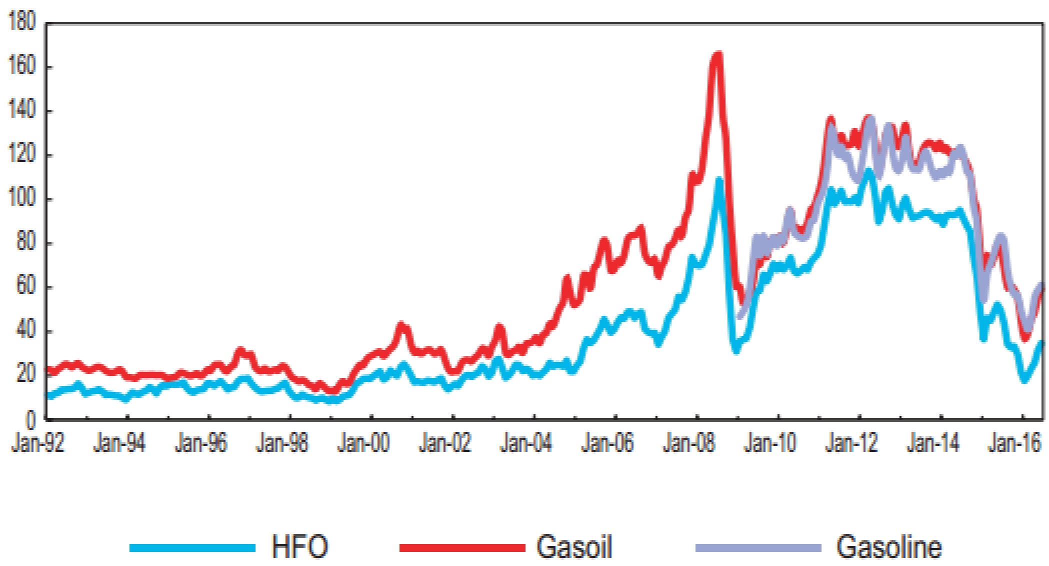
In the following Figures are shown energy prices for oil, oil products, coal and natural gas. All prices are taken from Argus Media Ltd, 2016.

Figure 1.14: Average key crude oil spot prices in USD/barrel.



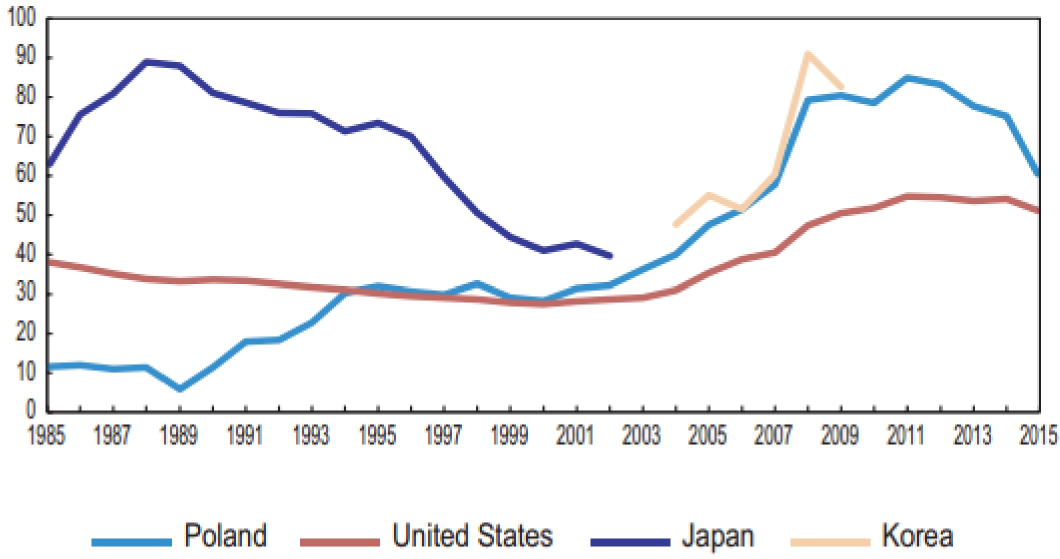
Source: Key World Statistics, IEA, 2016.

Figure 1.15: Average Rotterdam oil product spot prices in USD7barrel.



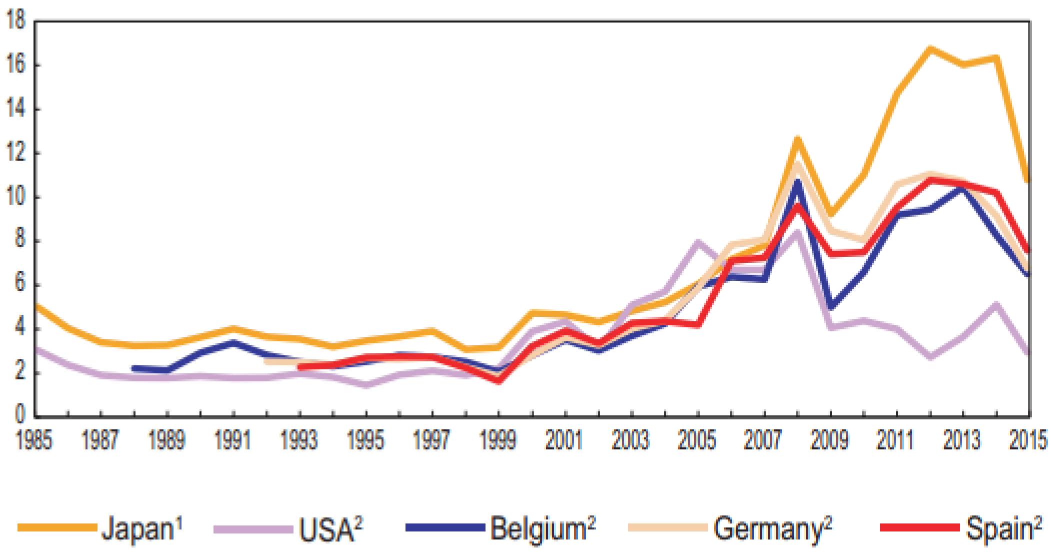
Source: Key World Statistics, IEA, 2016.

Figure 1.16: Average steam coal prices for electricity generation in USD/tons.



Source: Key World Energy Statistics, IEA, 2016.

Figure 1.17: Average natural gas import prices in USD/MBtu.



1. LNG.
2. Pipeline.

Source: Key World Energy Statistics, IEA, 2016.

Renewable energy generation costs have decreased too in many countries around the world in the period between 2010 and 2015 (IEA, 2016). According to IEA, this happened due to more effective and less expensive technologies, which enabled renewable energy to be more cost-competitive with fossil fuel-generated energy and more affordable for consumers. Moreover, renewable energy has been supported by policies aimed at boosting energy security and sustainability. High incentives are not needed anymore by some renewable technologies such as solar PV and onshore wind, but they remain key elements for others like wind, solar thermal electricity and bioenergy (IEA, 2016). According to IEA, some countries can effectively substitute fossil fuels with renewable energy sources. For example, in Brazil and South Africa onshore wind can be a cost-effective alternative to fossil fuels. On the contrary, in low fossil fuel price environment like for example United States, where the price of natural gas has been decreasing from 2014, fossil fuels still represent the more cost-competitive energy source. In these markets, further cost reductions related to renewable energy generation are needed (IEA, 2016).

1.3. Trends in renewable energy investments

Investment in renewables have increased a lot in the last dozen years, together with renewables awareness and sensitivity. In 2015, many advances in renewable energy technologies has been made, such as energy efficiency improvements, extended use of smart grid technologies and progress in energy storage. According to Bloomberg, New Energy Finance (BNEF), investment in renewables rose 5% to $285.9 billion last year. It represented a record compared to the peak in 2011 of $278.5 billion. The past record has been exceeded because 148 GW of capacity was added in 2015, equivalent to 53.6% of all power generation completed in 2015. Wind accounted for 63 GW installed and solar photovoltaics for 50 GW, while renewable heat capacity increased by 38 gigawatts-thermal (GW_{th}) and total biofuels production rose as well (UNEP/BNEF, 2016). According to BNEF, “the world now adds more renewable power net capacity annually than capacity from fossil fuels” (UNEP/BNEF, 2016); renewables are now able to supply 23.7% of global electricity (REN 2016). Table 1.2 shows the increase in renewable power capacity from 2014 to 2015 by sector.

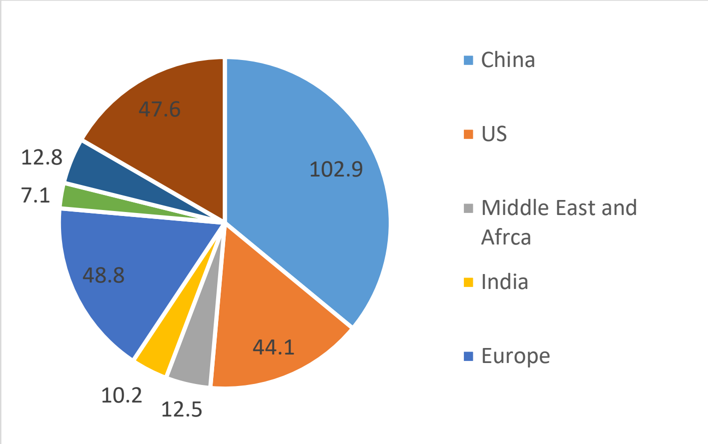
Table 1.2: Renewable Power Capacity additions by sector.

Power capacity	2014 (GW)	2015 (GW)
Renewable(total, not Hydro)	665	785
Renewable(total, including hydro)	1,701	1,849
Hydro	1,036	1,849
Bio	101	106
Geothermal	12.9	13.2
Solar PV	177	227
Wind	370	433

Source: Bloomberg New Energy Finance, 2016.

According to BNEF, the total amount committed from 2004 to 2015 has reached $2.3 trillion; it means more than $200 billion per year (UNEP/BNEF, 2016). Figure 1.18 shows the allocation of new investments among countries in 2015.

Figure 1.18. Regional split of new investments 2015, $BN.



Source: Bloomberg New Energy Finance, 2016.

Table 1.3 shows the sector split for global investment and percentage growth on 2014, excluding large hydro. It exhibit how wind and solar are becoming more and more important in renewables and how the other smaller sectors are losing relative significance. In fact, according to BNEF, Solar grew 12% on 2014 to $161 billion and wind increased 4% to 109.6 billion, while other sectors exhibit negative percentage growth compared to 2014.

Table 1.3: Global investments by sector.

Sector	**New investment**	**% Growth on 2014**
solar	161.0	12%
wind	109.6	4%
Biomass & waste to energy	6.0	-42%
Small hydro	3.9	-29%
biofuels	3.1	-35%
geothermal	2.0	-23%
marine	0.2	-42%
total	**285.9**	

Source: Bloomberg New Energy Finance, 2016.

According to BNEF, the year 2015 represents the year in which, for the first time, developing countries have invested more in renewables energies than developed ones (BNEF, 2016). All "developing countries" include non-OECD countries plus Mexico, Chile and Turkey (UNEP). Table 1.4 shows new investments by country in 2015. Developing countries dominated the rank for new investments in 2015 especially due to large commitments in China (BNEF, 2016). According to BNEF, developing countries accounted for 55% of the worldwide total investment, with $155.9 billion commitment; in particular, the "big three" invested $120.2 billion, the "other developing" economies $36.1 billion, 30% more than in 2014. Developed countries invested $130.1 billion, 8% less with respect to the previous year (BNEF, 2016).

Table 1.4: New investments by country.

Country	**New investments (2015, $BN)**	**% on total investment (2015)**	**2015 % growth on 2014**
China	102.9	35.99	17
Europe	48.8	17.06	-21
Asia (excl. China and India)	47.6	16.65	-2
US	44.1	15.42	19
America (excl. US and Brazil)	12.8	4.47	-3
Middle East & Africa	12.5	4.37	58
India	10.2	3.57	22
Brazil	7.1	2.47	-10
Total	**285.9**	**100**	**5**

Source: Bloomberg New Energy Finance, 2016.

According to BNEF, China was the leading country in total investment in renewable energy in 2015. As showed in table 1.5, China had a big margin on Unites States, that earned the second position, and it accounted for more than a third of global commitments. Investments consisted especially in asset finance and small-scale projects (BNEF, 2016). Next to China, the top investing nations according to BNEF were US and Japan, followed by UK that kept the fourth position it took in 2014. India exceeded Germany, which showed a huge drop in investment, with negative growth compared to 2014 (-46%). Brazil stayed unchanged at seventh place. South Africa re-entered the rank after leaving in 2014, showing amazing growth (+329%) at $4.5 billion as a wave of projects winning contracts in its auction program reached financial close. South Africa has been investing in particular in solar technology, given the solar power/sunshine abundancy. Africa is one of the most promising country for renewable energy, because its growing population, need for generation capacity and scarcity of electricity access in some areas. Chile appeared for the first time in the rank at 10th place (BNEF, 2016).

Table 1.5: Top 10 investing countries.

Country	**Investment in $BN**	**Growth on 2014**
China	102.9	17%
United States	44.1	19%
Japan	36.2	0.1%
United Kingdom	22.2	25%
India	10.2	22%
Germany	8.5	-46%
Brazil	7.1	-10%
South Africa	4.5	329%
Mexico	4.0	105%
Chile	3.4	151%

Source: Bloomberg New Energy Finance, 2016.

The details of the increase in capacity investment in 2015 for China, India and Brazil, are shown by Table 1.6. According to BNEF, China exhibited the largest jump in dollar terms in 2015, accounting for $14.7 billion of extra asset finance and $2.5 billion of additional small-scale project investments; Brazil and India increased their percentage of capital invested instead. The former reached 40% and the latter 34%, compared to China's 18% growth on 2014 (BNEF, 2016).

According to BNEF, significant investments on offshore wind were made in China in 2015; nine projects were financed, including three 300 MW projects, accounting for a total cost of $5.6 billion. Moreover, one solar thermal project of 200 MW was guaranteed, but greater commitments were given to onshore wind projects and PV, in line with previous years funding but up 9% and 18% on 2014 and with $42 billion and $43 billion secured respectively. China has commissioned a huge onshore wind plant of 29 GW, and has installed around 16 GW of new capacity in 2015 (BNEF, 2016).

According to BNEF, India increased its solar financings to $4.6 billion in 2015, up 75% on 2014. Big projects involved PV installations at 250 MW and 200 MW. PV projects in India became one of the cheapest in the world, at around $1.1 million per MW. The country has a solar target of 12 GW per year until 2022, much over the 3 GW installed in 2015. $4.1 billion of asset finance was devoted to the increase in wind capacity in 2015, 17% up the previous year, and 150 MW and 100 MW projects were two of the greatest projects financed. Anyway, some wind developers have moved to solar, perhaps seeing bigger opportunity, and this have delayed projects development time (BNEF, 2016).

According to BNEF, Brazil saw wind asset finance increase to $5.7 billion in 2015, up 46% on the previous year, and solar financings rose until $657 million. Big financed projects involved 260 MW and 144 MW capacity. Moreover, biomass received a significant financing of $2.3 billion for a 300 MW plant.

In Brazil, 2 GW of new wind capacity were installed in 2015. Anyhow, the construction of new transmission links resulted slower than expected, and the projects did not manage to benefit from tariff contracts completely, which majority were awarded to PV. In addition, development banks BNDES reduced the debt percentage they are willing to offer projects. This will probably force developers to for other borrowing options (UNEP/BNEF, 2016).

According to BNEF, China presented the most impressive increase in dollar commitments in the 2004-2015 period. In 2004, it invested around $3.1 billion, in 2010 about $41.6

billion (approximately 13 times what it had committed in 2004), until it hit the $102.9 billion record in 2015. It is the leading country for total capacity addition in hydropower, solar PV and wind power (BNEF, 2016).

Table 1.6: Increase in capacity investments in 2015.

country	**Asset Finance $BN**	**% growth on 2014**	**Small-scale Investment**	**% growth on 2014 $BN**
China	95.7	18%	5.5	81%
India	9.1	34%	0.4	12%
Brazil	7.7	40%	0.04	317%

Source: Bloomberg New Energy Finance. 2016.

Structures for clean energy require huge investments. As regard the types of financing mostly used in 2015 according to BNEF, Venture Capital invested $1.3 billion in renewable energy, private equity expansion capital $2.1 billion, Government Research & Development $4.4 billion, Corporate Research & Development $4.7 billion, technology/corporate level funding (represents equity raising by specialist renewable energy companies on the public market) $12.8 billion, acquisition activity $93.9 billion (represents the summing up of assets acquisitions, refinancing, corporate mergers and takeovers, and buy-outs), lastly, the biggest investor in 2015 was asset finance of utility-scale projects (for example wind farms and solar parks) which invested $199 billion (BNEF, 2016).

Since summer 2014, oil dropped in price from $115.71 a barrel (19 June 2014) to $ 27.10 on 20 January 2016, a downturn of 76% (BNEF, 2016). Natural gas price declined from around 4.50$ per MBtu (June 2014) to $1.91 in February 2016 (BNEF, 2016). These reductions in prices have influenced energy market equilibrium and international trade (IEA, 2016).

According to REN21, despite the recent reduction in price of fossil fuels, investments in renewables have not experienced big damages, except for the heating and coaling sectors, that did slow growth. However, renewable power generating capacity saw its largest increase ever. Indeed, there is not perfect direct competition between fossil fuels and renewables, except for few crude oil producing countries. Gas compete more directly with wind and solar, and also coal compete with renewables, but this contest largely depends on spot commodity prices. Gas prices have fallen in Europe and Asia but not at the same rate as they have fallen in US (REN21, 2016).

According to BNEF, renewables are now cost competitive with fossil fuels in many markets. Technological advances, expansion into new markets with better resources and improved financing conditions have reduced renewables costs in 2015. Infrastructures are faster to be built than coal, gas and nuclear plants. Solar parks take three-to-six months to be built and wind farms almost nine months, coal and gas plants need several years to be ended instead, nuclear even more. The quickness of plants construction represent a crucial reason why developing nations are opting for renewables nowadays, because of their urgency to add electricity capacity and need for more competitive and long term installations, considering also the shortage of fossil fuels remaining on Earth. Developing countries have invested especially on wind and solar technologies. Commitments on wind technologies amount to $67.4 billion, while developed countries invested $42.2 billion. However, the most impressive change happened with solar, that has always been dominated by developed countries until 2014. In 2015, the gap on solar investment between developed and developing nations shrink to less than $1 billion, thanks to China, India, Chile and South Africa that boosted their commitments (REN21, 2016).

Renewable energy have always been considered too expensive, but motivations listed before and fast rising electricity demand explain why developing countries invested so much in it recently. It is cost saving and will be more competitive in the future. Challenges have not gone, anyway. They include national electricity monopolies, lack of investor confidence, energy policy decisions, and variable generation and storage of energy.

1.4. Concerns and conflicts

Energy security and energy access are two important elements in the energy sector and are playing an increasing role in shaping the evolution in the sector. In fact, increasing importance is given to these two complex concepts and many tools such as investments and policies are implemented to satisfy energy security and access.

The IEA defines energy security as "the uninterrupted availability of energy sources at an affordable price". In particular, in a short run dimension, energy security refers to the ability of react promptly to sudden changes in energy supply and demand. Energy security in the long-run deals with investments needed to ensure the supply of energy "in line with economic developments and sustainable environmental needs" (IEA). Lack of energy security refers to unavailability of energy, non-competitive prices and high and volatile prices which cause problems or have negative impacts on economic development (IEA, 2014). These problems usually arise where there are capacity constraints or the market is not able to promptly balance supply and demand in the short term. Energy security has always been one of the aims of the IEA. In fact, IEA promotes alternative energies and encourage diversification in order to address energy security issue and oil import dependence. Historically, energy security has always been related to the supply of oil (IEA, 2011). According to IEA, as energy systems developed different vulnerabilities arose and other factors affecting energy supply should be considered. These additional factors include technical failures and disruptions, sudden increases in demand, dependence on energy imports and emergency stock (IEA, 2011). According to World Economic Forum, the shift towards more renewable energy is providing consumers with different sources of energy and therefore contributing to diversify the energy portfolio and improve energy security (WEF, 2016).

As regards energy access, a common definition has not been defined yet, but it refers to access to minimum level of electricity and safer and more sustainable energy that permits to improve economic activities and public services (IEA). Technical availability, adequacy and reliability of energy are all faces of energy access. IEA's definition of energy access includes different amounts of minimum level of electricity needed to a household, varying with the area considered (urban or rural). According to IEA, energy is fundamental to improve the economic condition of countries and living standards of people, and the access to sustainable and reliable energy is the key to achieve these objectives and foster equity around the world (IEA, 2014).

Besides energy security and access, other issues are characterizing energy market in the past few years, like low oil and natural gas prices, conflicts for the control over energy sources and environmental concerns (IEA, 2016).

According to REN21, in recent years the energy market has been characterized by low oil prices. In fact, since summer 2014, oil dropped in price from $115.71 a barrel (19 June 2014) to $ 27.10 on 20 January 2016, a downturn of 76%. Natural gas price declined from around 4.50$ per MBtu (June 2014) to $1.91 in February 2016. Despite the recent reduction in price of fossil fuels, renewables have not experienced big damages, except for the heating and coaling sectors, that did slow growth (REN21, 2016). However, according to BNEF, renewable power generating capacity saw its largest increase ever (UNEP/BNEF, 2016). Indeed, according to REN21, in the short term, there is not perfect direct competition between fossil fuels and renewables, except for few crude oil producing countries. Gas compete more directly with wind and solar, and also coal compete with renewables, but this contest largely depends on spot commodity prices (REN21, 2016).

According to IEA, the drop in oil prices will have huge repercussions at a global level and influence international relations and political developments if the price will not balance the market in the next years. In fact, today's low oil prices may be good for importers and consumers, but not for companies working in the energy field and for countries which highly rely on revenues from oil trade. Due to low oil prices, many high-cost oil producers and oil-producing regions are operating on the red. For example, the 70s oil crises has given new importance to the Middle East and contributed to the collapse of the Soviet Union (IEA, 2015). During the 2015 World Energy Outlook presentation, IEA predicted that, given supply difficulties and growing energy demand, oil prices will gradually recover to balance the market again in 2020. According to their prediction, oil prices will achieve $80. IEA considered also a low price scenario ($50 per barrel) and the implications that would come from that. Oil importers would enjoy economic benefits, but since revenues from oil production would be significantly lower, also oil production would decrease and concentrate in few low cost countries in Middle East, which would meet the 75% of global oil export (today is around 50%). This could be a problem for oil security, since geopolitical issues in that area are not going to be solved any time soon and reliance on Middle East oil would get back to 1970s levels. Moreover, according to IEA, lower prices would cut essential policy support for energy efficiency. Their predictions show that at least 15% of efficiency savings would be lost and policies support for renewable would be difficult to legitimate in a low, long-term energy prices contest. This low oil price scenario implicates low oil production and high demand; for these reasons, IEA consider this scenario unlikely (IEA, 2015).

Moreover, low oil prices can give rise to geopolitical conflicts in the future. In history, there have always been violent conflicts all over the world fueled by energy resources, some of them are still happening now. The desire to control valuable fossil fuel assets, especially crude oil and natural gas, has always led to wars and tensions. In a world in which energy demand is growing fast, it is not surprising that those commodities and sources of income cause rivalry and competition between neighbors. Michael Klare, Professor of Peace and World Security studies at Hampshire College in Massachusetts, said:" in a fossil-fuel world, control over oil and gas reserves is an essential component of national power". In fact, countries endowed with huge fossil fuel resources have political power over nations in need for fossil fuel and can influence the world stage. Despite conflicts may have different fueling factors, such as different political or religious inclinations or eruption of historic antagonisms, many of them hide struggles for control over fossil fuels reserves, that is, the principal source of national income. Iraq, Syria, Nigeria, South Sudan, Ukraine, The East and South China seas are areas where the majority of these conflicts have taken place. The Iran-Iraq War of 1980-1988, the Gulf War 1990-1991 and the Sudanese Civil War of 1983-2005 are examples of struggles driven by energy resources (Michael Klare, 2012).

According to Michael Klare, most recent fighting may be less evident, but most of them are energy war too (Michael Klare, 2014). Michael Klare discussed some of those cases such as the Iraq-Syria-ISIS case, the Ukraine-Russia and Crimea case, the Nigeria case, the South China Sea case and the US-Saudi Arabia case (Michael Klare, 2014).

In the Iraq-Syria-ISIS case, every faction playing a role in the fight is trying to occupy key oil-producing areas in Syria and oil-refining facilities in Iraq, in order to gain unique position over the counterparts. Being able to sell oil means having the funds necessary to continue the fight and control over buyers. On the other hand, even deny oil supplies or restock is part of their strategy.

In the Ukraine-Russia and Crimea case, the war has been about political legitimacy and national identity, but actually, Ukraine represents a key distributor for Russia, a mean for natural gas delivery to Europe. The old Ukrainian government has refused to sign the agreement with EU, agreement that now has been signed by the new Ukrainian government. The agreement calls for the extensions of European's energy rules, norms and standards to Ukraine in order to facilitate internal market. Given Russian reliance on natural gas sales to Europe, the agreement was not convenient for Russian (and Ukraine) elite. This lead to internal protests and collapse of old government in Ukraine. Negotiations over gas price remain a big issue between Russia and Ukraine. Moreover, the annexation of the Crimea into Russia increased its offshore control over the Black Sea, which is thought to host great reserves of oil and natural gas.

In the Nigeria case, high government corruption leave population starve and subsist on less than $2 per day, while big money enter into the pockets of the elite. In Sudan, a second civil war was fueled by oil discovery in South Sudan. The latter, had gained more autonomy with respect to the rest of Sudan after years of war, but when oil was discovered the struggle started again. The country become independent in 2011, after many years of battles and after an agreement with North Sudan, the only distributor of South Sudan oil resources. In the South China Sea case, China, as the biggest consumer of energy, is trying to gain power over the South China Sea under the excuse of nationalistic impulses related to past territorial losses. Actually, huge oil reservoirs are thought to be located in that territory.

Finally, another interesting example is represented by the shale oil, which is an unconventional oil produced from oil shale rocks. Through pyrolysis, hydrogenation or thermal dissolution the organic matter within the rock is transformed into synthetic oil, and can be used in place of conventional oil. Shale oil has been used in the past, since crude oil was discovered in Middle East and its production arrested because less convenient than that of crude oil. Following the current oil crises, production or exploration of shale oil started again in US, China, Australia and Jordan. Shale oil was expected to gain significant importance especially in USA, which was predicted to gain particular independence from oil imports (IEA, 2014). According to IEA, majority of shale oil should be sold at $50 per barrel in order to reach the break-even, but investments and infrastructures should also be considered. With Brent at $47 and WTI at $44, investments in shale oil declined and its competitiveness decreased. Saudi Arabia has been the major responsible of the decrease in crude oil prices, because it wanted to exclude shale oil from the market. It calculated that low oil prices would have arrested the production of shale oil, but they have made difficult the production of conventional oil even in OPEC members (EIA, 2015).

Ethnic and religious divisions can provide a political or ideological fuel for these fighting, but in a world were fossil fuels are central, potential for profit and power should be considered in the whole picture.

In the end, environmental concerns and issues must be taken into account. According to IEA, the planet is currently facing several environmental problems such as natural disasters, changing in weather conditions and warming and cooling periods that did not exist before. Environmental problems make humanity vulnerable to disasters and tragedies, and huge efforts are needed to fix current situation. Population worldwide is definitely responsible for that, and needs to change habits and addictions to protect the planet. In fact, energy production and use are by far the largest sources of pollution provoked by humanity (IEA, 2016).

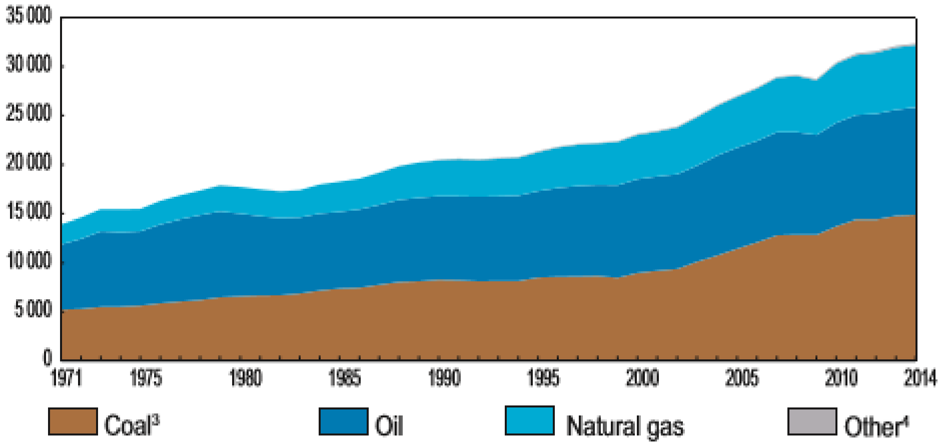
Specifically, according to IEA, (IEA, 2016) environmental problems are:

- Pollution. Air, soil and water are seriously polluted. Industries and motor vehicles have highly contributed to pollute, releasing various gases, toxins and industrial waste. Clean water is becoming a rare commodity especially in less developed nations. Now, millions of years are needed in order to recoup.
- Global warming and climate change. High level of emissions of greenhouse gases have led to rising temperatures of the oceans and the Earth surface. This caused rising sea levels, melting of polar ice caps, changing in seasons, unnatural precipitations or excessive snow and desertification.
- Natural resource depletion. Consumption of natural resources has increased as population and demand for food and energy increased. Worldwide, nations have always relied on fossil fuel for the production of energy. Reserves of fossil fuel have been used up, and will probably finish soon; to solve this problem, researchers are investigating new ways to produce energy. Moreover, the over consumption of resources has led to the problem of waste disposal. Waste and garbage need a lot of space. Huge quantities are dumped in oceans or in less developed countries, contributing to water pollution and land grabbing.
- Loss of biodiversity. Growing population and human practices need space and land to develop. Some eco-systems have been irreparably destroyed or modified. Increasing deforestation highly contributed to loss of biodiversity.

- Ozone layer depletion. Pollution has weakened the ozone layer that is not able to completely protect us from the sun's harmful rays.
- Risk to human health. Health diseases, allergies and intolerances have become very common in the last decade. According to IEA, around 6.5 million premature deaths each year can be attributed to air pollution.

All environmental issues described before can be addressed by reducing pollution, therefore limiting emissions of greenhouse and other toxic gases, reducing waste and natural resource usage. The spread and development of renewable energy is one of the most practical and cost-effective ways to immediately address climate change and fossil fuel limitation in supply. In fact, people has always relied on fossil fuel for energy production, considering it as a quick way to meet energy demand. Nowadays, global warming related to climate change and concerns about scarcity of fossil fuel reserves push research and development to investigate new techniques to produce green and renewable energy.

Figure 1.19: World CO2 emissions from fuel combustion from 1971 to 2014 by fuel (Mt).



Source: Key World Energy Statistics 2016, IEA.

According to IEA, the major greenhouse gas emitted by human activities are carbon dioxide (65% of the global total), methane (16%), nitrous oxide (6%) and fluorinated gases (2%). Global carbon emissions from fossil fuels have increased by about 90% since 1970, reaching 32,381 Mt of CO_2 in 2014. Coal contributed to 45.9% of total carbon dioxide emissions, oil to 33.9%, natural gas to 19.7% and industrial waste and non-renewable municipal waste to 0.5%. Global top polluters in 2014 were OECD countries with 36.6% of total CO_2 emissions, China with 28.2%, Asia with 11.8%, non-OECD Europe and Eurasia with 7.6%, Middle East with 5.3%, non-OECD Americas with 3.6%, Bunkers with 3.5% and Africa with 3.4% (IEA, 2016).

1.5. Policy support

The year 2015 was a crucial one for what concerns renewable energy agreements and announcements. Countries around the world continue to develop new policy measures for renewable energy that remove barriers, attract investment, drive deployment, foster innovation and encourage greater flexibility in energy infrastructure (REN21, 2016). In particular, The United Nations General Assembly (UNGA) adopted a dedicated Sustainable Development Goal on Sustainable Energy for all (SDG 7), and, at the end of the year at the United Nations Framework Convention on Climate Change's (UNFCCC) 21st Conference of the Parties (COP21) in Paris, 195 countries established to decrease global warming below 2 degrees Celsius.

According to REN21, the G7 countries committed to strive "for a transformation of the energy sectors by 2050" and to "accelerate access to renewable energy in Africa and developing countries in other regions." (REN21, 2016).

According to REN21, G20 member countries account for 63% of the world population and 82% of global GDP. They also account for 93% of the world's coal, 93% of global solar capacity, 98% of wind capacity and France and US alone account for about half of global nuclear power capacity. During the G20 Energy Ministers Meeting, the participants confirmed their commitment to renewable energy and energy efficiency, and agreed on a G20 Energy Access Action Plan for sub-Saharan Africa, in order to exploit the great potential of the region.

For the first time, a dedicated goal on sustainable energy for all has been insert in the 17 Sustainable Development Goals (SDGs) adopted in the United Nations (UN) General Assembly. The Sustainable Energy For all (SE4All) aims to increase energy access.

Other noteworthy commitments included a US-China Joint Presidential Statement on Climate Change regarding new domestic policies on renewables and energy efficiency. China is the world's biggest polluter, contributing 20.09% of total emissions, the US is the second polluter, with 17.89% of global emissions. The world's two biggest polluters have ratified the Paris climate deal, and the agreement is one-step closer to come into effect (REN21, 2016).

According to REN21, the European Union (EU) devoted to a binding regional target of 40% domestic reduction of greenhouse gas emissions by 2030 (from a 1990 baseline), and renewable energy and energy efficiency targets. The International Solar Alliance (ISA) was created by the presidents of France and India to boost solar energy deployment in more than 120 sun-endowed countries. The ISA aims at improving energy security, sustainable development, access to energy and living standards. The African Renewable Energy Initiative (AREI) was launched and aspire at having 300 gigawatts (GW) of renewable capacity by 2030. The leaders of the Climate Vulnerable Forum (CVF) aim at 100% renewable energy by 2050 in the Manila-Paris Declaration. The growing global movement for 100% renewables also propagate from the Paris City Hall Declaration (. Nearly 1,000 city mayors signed the declaration and accepted 100% renewable energy or 80% reductions in greenhouse gas emissions by 2050. The private sector also strengthened its commitments to renewable energy in 2015. More than 50 of the world's largest companies devoted to get 100% of their electricity from renewable sources (REN21, 2016).

According to REN21, most countries adopted support policies such as targets, mandates, incentives and enabling mechanisms in order to mitigate global climate and to express their commitment to renewable energy diffusion. 173 countries have improved their targets in 2015, setting long-term and even provincial-level targets, which are achieved by adopting specific regulatory measures, fiscal incentives and public financing options. Anyway, even if targets represent an important tool to perceive renewable energy objectives, they do not guarantee success.

Policy makers mainly focus on policies for electricity, namely on renewable power generation technologies, especially solar PV and wind power. Indeed, 110 jurisdictions enacted feed-in policies in 2015, both at national and provincial level. "Feed-in policies" are a tool to encourage the use and accelerate investments in renewable energies. Also tendering has grown a lot in recent years. In 2015, more than 64 countries have adopted renewable energy tenders. "Tender" is a mechanism for allocating financial support to renewable energy projects. Tenders consider price but also additional criteria in order to evaluate a project, differently from auctions, where the only important thing is price.

Fiscal policies, such as grants, loans and tax incentives represent important incentives for renewable energy technologies development as well.
Policies to support heating and cooling sectors did not improve through the whole 2015, and it remained below other sectors. Fiscal incentives are the major tool to support these sectors, so is difficult to finance big projects. Indeed, the majority of renewable heating and cooling technologies are on a small-scale, on a residential or commercial level.
As regard renewable energy transport policies, the greater number of policies adopted in the sector in 2015, regarded biofuels supported road transport (REN21, 2016).
According to Bloomberg New Energy Finance, many countries around the world have met and risen their targets regarding more sustainable and green energy use in 2015.
Many countries in Africa have increased and achieved their targets in 2015, in fact the majority of African countries have completed their National Renewable Energy Action Plans. Moreover, African targets are among the highest worldwide.
Europe adopted a new regionally binding target, aiming to a minimum of 27% renewable energy in final energy consumption by 2030, through the adoption of feed-in tariffs (FITs) and tendering mechanisms. Support for renewable heat increased in 2015, and more regulations were introduced to meet the 2020 transport goal.
The Latin America and Caribbean area is one of the most competitive in the bid for renewable energy project allocation, and one countries setting the more ambitious targets in the world.
New net metering policies and new fiscal incentives were introduced in Middle East to support renewable power projects, and tenders expanded in Iraq, Jordan and the United Arab Emirates.
Since 2014, net metering incentive, investments and production tax credits were launched and amplified in North America. Many states extended existing Renewable Portfolio Standards.
Multiple Pacific Island nations introduced 100% renewable energy targets in 2015. India and China augmented their targets; India, specifically, expanded policies and adopted new net metering policies and tendering use in order to promote renewable power diffusion and deployment (BNEF, 2016).

2. The Case of China

Over the past 30 years, China has experienced rapid industrial development and economic growth rate of around 10% since 1980, representing the fastest major economic expansion in history (World Bank, 2014). Although growth rates differed among provinces in China, growth was rapid everywhere. Since first market reforms in 1978, China managed to shift from a centrally- based economy to a market- based one (World Bank, 2014). Today, China is one of the largest economies in the world and the first manufacturer and exporter worldwide (IEA, 2015). With its population of 1.3 billion, it is becoming increasingly important and influential in the global economy (World Bank, 2015). However, China remains an emerging country, since its per capita income is still a fraction of the one of developed nations (World Bank, 2014). Although, it is continuing to catch up with developed nations, albeit more gradually. In the lag of time considered, China has achieved many other achievements in health, education, science and technology. Many unique factors has let China accomplish such rapid growth, including initial conditions of the economy and sustained reforms that has been made since 1980 (OECD, 2015). In particular, China has introduced market- oriented reforms, "supporting state-owned firms in old priority sectors while liberalizing and encouraging the development of private enterprises" (Lin 2012). Different areas were able to adopt their unique institutions that more suited their particular circumstances and needs and were allowed to compete between each other in improving the local business environment. Decentralization policies gave the resources necessaries to local governments to achieve local development objectives, and stimulate competition that became a strong driver of growth. Economic growth became a national objective, and governments, firms and individuals focused their effort on economic development (OECD, 2015). To sustain this rapid economic and structural change, the government created new job places and employed an average of 9 million workers each year, while absorbing labor force affected by policy shifts and structural changes (World Bank, 2015). 800 million people was lifted out of poverty in the transition from low-income to medium-income status, even if there were still 70.17 million poor people in rural areas in 2014 (World bank, 2015). Crucial monetary and fiscal policies were able to effectively maintain stability, despite macroeconomic challenges such as inflation that took place in the early 1990s (World Bank, 2015). Finally, two key elements of the reforms which allowed China to sustain fast economic growth have been domestic and global market integration. Internal barriers to trade and free movement of goods, capital and labor were destroyed, allowing domestic firms to achieve economies of scale. Moreover, with the accession into the World Trade Organization (WTO) in December 2001, China expanded its economic integration with the global economy (World Bank, 2015).

In the following chapter, Chinese production and consumption of energy and related trends are described in detail. Investments, concerns and prospects regarding renewable energies are also illustrated at the end of the chapter.

2.1. Energy Supply and Demand

China is the most populous country and, since 1980, it undergo a period of rapid economic growth and development. In developing countries, high economic growth means high energy needs to support this expansion and sustain higher living standard of the population. Its fast-growing economy has made China the largest energy user worldwide. Nowadays, China is trying to diversify its energy mix, in order to decrease its dependence on fossil fuels and imports. Most of the Chinese electricity production comes from coal, followed by oil, hydro, wind and other renewables (IEA, 2016). According to British Petroleum (BP, 2016), China will become the first energy importer worldwide by 2035. In fact, China is expected to increase its share of global energy consumption to 25%, and its share of global energy production to 20% in 2035 (BP, 2016). According to BP, coal will keep its dominance in China’s energy mix but it will decline to 47% in 2035, compared to 66% in 2014. Natural gas will increase and reach 11% in the total energy mix and nuclear capacity will account for 31% of global total, while oil share will remain unchanged at around 19% (BP, 2016).

Oil

According to EIA, China's total oil production has increased about 50% over the past two decades, but after the peak in 2010, it has shown more moderate oil production (EIA, 2015). In 2014, China produced almost 4.6 million oil barrels per day, but it supplied only its domestic market, even though it was not able to serve its overall demand (IEA, 2014). Based on the International Energy Outlook 2014 (IEO2014), IEA forecasts that oil production in China will grow to 5.1 million barrels per day (bll/d) by 2020, 5.5 million bll/d by 2030, and 5.7 million bll/d in 2040. Recent energy policies was developed in order to improve domestic production of oil and invest on technologies able to extract oil in deep water, complex geological reserves or mature fields (EIA, 2015). Major oil fields in China are located in the northeast and north central regions of the country, but they are mature and have been heavily exploited since the 1960s, so their output is expected to decline in the next decade (EIA, 2015). According to EIA, considered the country's dependence on energy and on oil imports, China is trying to extrapolate as much as possible from its challenging oil fields (although low oil prices of last years has slowed down this practice), but it is also purchasing and investing in international oil and gas assets since 2008, in order to secure more oil and gas supplies. Chinese companies are participating in upstream activities in 42 countries, especially in Middle East and Africa, where half of their overseas production took place. According to EIA, China has invested around $73 billion in overseas oil and gas assets between 2011 and 2013, and made acquisitions in the Middle East, North America, Latin America, Africa and Asia. These upstream acquisitions not only constitute commercial opportunities, but also the chance to gain technical expertise in challenging and unconventional plays. Chinese foreign oil production from international equity shares and acquisitions have significantly risen in the past few years. In 2010, China's overseas production was 1.36 million bll/d, in 2013 it rose to 2.1 million bll/d, most of them come from Iraq (26% of total in 2013), and other major contributions from Kazakhstan, Sudan and South Sudan (EIA, 2015).

According to EIA, by the end of the 2013, China has established several oil-for-loan deals with different countries amounting to $150 billion, in which it guarantees capital to extract energy reserves or build energy infrastructures in exchange for oil and gas imports at established prices. Countries that have signed oil-for-loan deals in the past decade are Russia, Kazakhstan, Venezuela, Brazil, Ecuador, Bolivia, Angola and Ghana (EIA, 2015).

Oil imports in China have increased dramatically over the past decades, due to high domestic demand exceeding domestic supply. For this reason, according to EIA, China has diversified its sources of crude oil in several regions and investments to guarantee adequate imports. Saudi Arabia and Angola constitute the main sources of crude oil imports in China, and together they account for 29% of total oil imports. In 2014, EIA estimated that the Middle East supplied China with 3.2 million bbl/d (52% of total oil imports), Africa with 1.4 million bbl/d (22%), and other countries include America with 667.000 bbl/d (11%), Russia with 778.000 bbl/d (13%), and the Asia-Pacific region with 127.000 bbl/d (2%). Other countries supply the remaining 27.3000 bbl/d (less than 1%). Specifically, as stated by the Global Trade Information Services (IEA), top oil importers in 2014 were Saudi Arabia (16%), Angola (13%), Russia (11%), Oman (10%), Iraq (9%), Iran (9%), Venezuela (4%), United Arab Emirates (4%), Kuwait (3%), Colombia (3%), Congo (2%), Brazil (2%), South Sudan (2%), Kazakhstan (2%), others the remaining 9% (EIA, 2015).

According to EIA's estimates, China's dependency on oil imports has increased from 30% in 2000 to 57% in 2014, despite Chinese government has been trying to create more sustainable economic growth and substitute oil with other sources of energy. The country's need for energy has made it the first petroleum and other liquids importer in the world, surpassing US in 2013 (EIA, 2015).

China has diversified its imports from different countries, but also through different pipelines to diversify oil import routes. In fact, according to EIA, China has improved the integration of its pipeline network to establish more international connections a ensure supply of energy. According to China National Petroleum Corporation (CNPC), Chinese domestic network accounted for 15.657 miles of total crude oil pipelines and 12.605 miles of oil products pipelines by the end of 2013. Transnational oil pipelines link China with Kazakhstan, Russia and Myanmar. The first transnational oil pipeline was inaugurated in 2012, and it is still used to transport oil from Atyrau in Kazakhstan to Alashankou on the Chinese border. It was developed by a joint venture between CNPC and KazMunayGas (KMG), and financed by Chinese loans. Its initial capacity was 200.000 bbl/d, but it was later expanded in 2013 to 400.000 bbl/d. International imports from Russia take place through the Eastern Siberia-Pacific Ocean (ESPO) pipeline. This pipeline was constructed by the Russian Transneft in two stages, the second one connecting Russia to the Chinese border; operational from the early 2011, it is able to deliver up to 300.000

bbl/d of Russian oil. Russia augmented contracted oil supply to China starting from 2020 through the sea route from the Russian Pacific port of Kozmino. Finally, imports from Myanmar occur through a pipeline operational from January 2015. This pipeline is thought as an alternative route to transport oil from the Middle East, in order to avoid the potential choke point of the Strait of Malacca, where the majority of China's imports traverse (EIA, 2015).

As stated by EIA, China also holds the biggest oil strategic reserves in the world, which is stockpiles of crude oil preserved for national security in case of energy crises. The country is building oil strategic reserves as "energy supply security policy" to secure adequate oil supply and mitigate geopolitical risks and uncertainties involving global oil supply. In doing it, China has diversified its sources of crude oil in several regions and investments to guarantee adequate imports. According to EIA, China held 24.6 billion barrels of proven oil reserves in 2015 (EIA, 2015). This government-administered strategic petroleum reserve program (SPR) was firstly established during the 10th Five-Year Plan (2001-2005), and articulated in three stages. The first stage was completed in 2009, and held 91 million barrels of total storage at four sites. The second stage is expected to add about 170 million barrels of capacity by 2020, and the last stage is supposed to add other 232 million barrels (EIA, 2014). EIA estimates that China held almost 350 million barrels of commercial crude oil storage in 2014, in addition to the strategic reserve of crude oil. A clear definition of the difference between commercial and strategic crude oil reserves has not been defined yet, but both depend on supply security, oil prices, domestic demand, domestic policy and storage capacity build (EIA, 2015).

As stated by EIA, China's oil sector is widely influenced by national oil companies. The major state-owned companies have been established in the 1980s, the China National Petroleum Corporation (CNPC), the China Petroleum and Chemical Corporation (Sinopec), and China National Offshore Oil Corporation (CNOOC). They are specialized to operate in various areas of the oil sector. CNPC was given responsibility of the China's onshore upstream assets, Sinopec was put in charge of refining, distribution and petrochemicals activities, and CNOOC was responsible to explore and develop offshore oil and gas assets of the country. Nowadays, CNPC is the leading upstream company in China, and is seeking more downstream market share, Sinopec is trying to get more upstream asset to gain more benefit from oil and gas production and CNOOC hugely expanded its role due to increasing importance given to offshore areas and overseas assets (EIA, 2015).

Natural Gas

China more than tripled natural gas production in the decade between 2003 and 2013, rising to 116 bcm, and hit 124 bcm in 2014 (EIA, 2015). The majority of gas consumption regarded industry sector, but the shares of gas consumption increased also in the power and transportation sector (EIA, 2015). According to EIA, Chinese government is boosting natural gas production and use in order to replace other hydrocarbons in the country's energy mix. By 2020, at least 10% of total energy consumption would concern natural gas in order to alleviate high levels of pollution deriving from heavy coal use (EIA, 2015). According to data released by the Oil and Gas journal, EIA stated that China held almost 4644 bcm of proved natural gas reserves in 2015, the largest estimated in the Asia-Pacific region (EIA, 2015).

According to EIA, many regions in China are gas producers. Until 2007, China was a net gas exporter, but afterwards it became a net gas importer; natural gas imports met 32% of demand in 2013 (EIA, 2015). According to EIA, the increasing demand for natural gas in China has made the country the third biggest gas importer worldwide in 2012. To meet high demand for natural gas, China has diversified its imports between Qatar that was the biggest importer of natural gas in 2014, Southeast Asia and Australia. In 2014, 28.80 bcm were imported in China, rising by 7% with respect to the year before. Almost half of natural gas imports took place through pipelines, in the form of liquefied natural gas (LNG) (EIA, 2016). 12 terminals are operational in the LNG import sector, and imports are expected to keep rising since other eight terminals are under construction (EIA, 2016). CNOOC is a key player in China in the regasification of LNG, and at the end of 2013 it completed the first floating storage and regasification unit in China (FSRU). Other three FSRU are under construction (EIA, 2016). The NOCs operate in seven of the existing terminal plants, and have made many advances in LNG sector. CNPC and Sinopec entered the market respectively in 2011 and 2014 (EIA, 2016). According to EIA, Chinese companies are investing also in coalbed-methane and shale-gas liquefaction projects, which are supposed to begin operations in 2020 (EIA, 2016).

According to EIA, the country's increasing natural gas demand has boosted the development of different frontiers plays as deep-water, shale gas, and gas derived from coal seams. The first deep-water field entered operations in 2014, and other offshore areas are gaining increasing importance in the natural gas developments in China. In fact, China's NOC are intensively exploring deep-water areas in the eastern South China Sea in order to replace diminishing reserves of gas. According to EIA, the NOC produced around 4.9 bcm in the South China Sea in 2014 (EIA, 2015).

Even though many challenges are related to coalbed methane (CBM), coal-to-gas (CYG) and synthetic natural gas (SNG), they are under exploration. Technical challenges, regulatory issues, transportation constraints and competition with other fuel resources has slowed down researches, but these sectors' potential has driven government to search for foreign investors with technical expertise to exploit these opportunities. CBM production was estimated at 16.35 bcm in 2014, from both surface wells and coalmines, even if most of the production was from coalmine extraction (EIA, 2016). According to EIA, coalbed methane production is increasing although developers are facing many problems such as lack of infrastructures, high development costs, regulatory and technical issues and competition with other natural gas forms. A policy guideline was issued by China's State Council at the end of 2013 to solve some regulatory issues; it stated that the central government held rights on natural gas and CBM while local governments had rights to coal mines. In the guideline, investments in CBM development and pipeline infrastructures was encouraged. The first operational CBM pipeline was in 2009, and it connected the Qinshui Basin to the West-to-East pipeline. Nowadays, many other pipelines are under construction or have become operational (EIA, 2016).

According to EIA, coal-to-gas projects have gained increasing consensus because it can exploit country's abundant coal resources. Although promising premises, CTG industry has experienced little progresses and targets has not been reached, since plants are operating at low rates. Other large-scale CTG projects are under construction, but high development costs and level of emissions may affect their potential (EIA, 2016).

As regard shale gas, according to EIA this industry has great potential in China, given its large recoverable shale gas resources, the largest in the world, amounting to 33.45 tcm in 2015 (EIA, 2016). Shale gas industry is still at the beginning, due to many challenges such as lack of technical skills, high drilling costs and necessary investments in infrastructures and research. Despite these issues, production has risen more than five times in the period between 2013 and 2014, to 1.26 bcm (EIA, 2016). Although, it was less than expected. According to EIA, production was estimated to reach 6.44 bcm at the end of 2015, a total unrealistic figure (EIA, 2016). According to EIA, other types of natural gas would take precedence in the near term, but shale gas will play an important role after 2020, since shale gas is expected to have a significant potential in China (EIA, 2016).

Natural gas sector organization is similar to oil one. As with oil, natural gas exploration and production are dominated by the principal state-owned oil and gas companies: CNPC, Sinopec and CNOOC. CNPC is specialized in upstream and downstream sectors, and is the largest natural gas company in China. According to Facts Global Energy (FGE), it accounted for almost 77% of total production in 2014 (FGE, 2015). Sinopec operates in one of the most promising Chinese field in Sinchuan Province, and CNOOC manages most of the country offshore production and the development of the first three import terminals. According to EIA, China's oil and gas companies has invested in shale oil and gas plays in North America in order to gain technical expertise in the area.

The rapid increasing natural gas demand in China has created new opportunities for private energy companies too, which have attracted private interest and investments. Many local state-owned municipalities own minority stakes in terminals and facilities. In 2014 was issued a new policy giving wider access to third parties in the supply of natural gas. For example, tendering is available to NOCs, but also to private and local enterprises and foreign investors, which have a contract with a participating Chinese firm. Anyway, state-owned companies own the majority of gas resources and partner with foreign companies due to lack in technical expertise and investments to develop these projects.

In response to changing scenario of China's natural gas supply, the government has implemented price reforms to adapt domestic gas prices to international ones (EIA, 2016). Natural gas prices, as well as oil prices, are regulated by the National Development and Reform Commission (NDRC), which before the reforms has kept prices well below international market ones. The rapidly increasing natural gas market in China has forced gas prices to uniform, since imports, that were more expensive, have begun to compete with domestic production (EIA, 2016). Starting from 2011, the NDRC has developed a system to link domestic gas prices to international ones, in order to make domestic gas more competitive with imported gas and other fuels. The price reform applied in three stages. In 2011, China launched a "pilot phase", which applied only to some Chinese provinces, and after 2013 it enlarged the reform on a national basis, in a three –phase reform. The first phase linked natural gas prices to the one of imported natural gas and oil. Natural gas price was slightly discounted to encourage the use of gas over coal. Moreover, the reform did not apply on shale gas, coalbed methane and coal-to-gas but raised the price of 15% for non-residential consumers. This reform created two categories of price, the "tier 1" that comprised demand below 2012 level, and "Tier 2",which was more expensive, for higher demand. Phase two in 2014 rose prices for Tier 1 by 20%, while leaving unchanged the price of Tier 2. At the same time, market-based-prices was created for all types of imported gas, allowing sellers to make independent sales agreement and sell directly to buyers. In the third phase in 2015, China made a weighted average of the prices of Tier 1 and Tier 2 made the price uniform for all consumers (EIA, 2016).

According to EIA, the natural gas pipeline infrastructure in China is fragmented, but NOCs are highly investing in its expansion, in order to connect the production areas in the western and northern regions to the demand centers as well as distribution networks. According to EIA, natural gas pipeline accounted about 35498 miles at the end of 2013, but China expects to expand its network to 74564 miles by 2020 (EIA, 2016). CNPC is the main operator in the gas pipeline area, after recent investments in gas retail and pipeline projects to facilitate increasing gas supply. It includes also the West to East gas pipelines, central to connect major natural gas production areas in western China to demand zones in the eastern part of the country.

According to EIA, international pipelines have had a key role in the last years. In fact, since infrastructures and production of natural gas throughout Asia have increased, China's total imports have risen. Specifically, gas imports by pipeline in 2014 rose by 20% compared to the year before, to 32.08 bcm/y. The Central Asian Gas Pipeline transports gas by three pipelines from Turkmenistan, Uzbekistan and Kazakhstan, and its current capacity is 53.77 bcm (EIA, 2016). According to EIA, the China-Myanmar gas pipeline became operational in 2013, and by 2014 imported 3.5 bcm. (EIA, 2016).

Finally, in 2014 China agreed to buy 36.79 bcm from Russia over a 30-year period. The pipeline connecting Siberian fields to northeastern China are expected to come online in 2018 (EIA, 2016).

Coal

China has been the biggest consumer and producer of coal worldwide since the 1980s. According to BP, total coal reserves worldwide were estimated at 891531 million tons in 2015, and China accounted for 12% of them (BP, 2016). Thanks to China's vast coal resources, the country was able to support the impressive economic growth it undergone over the past decade, accounting for almost half of total coal consumption (EIA, 2016). According to EIA, the intensive utilization of China's coal resources is responsible for the world energy-related emissions; in fact, from 2012, the country has issued strict environmental regulations on high-polluting industries to address environmental pollution, and coal consumption started to decelerate. Chinese production and consumption of coal has declined by around 3% between 2013 and 2014, representing the first decrease in the industry over the past 14 years. This trend also reflects "the economic downturn particularly in coal-consuming sectors such as steel and cement, slower electricity demand growth and greater hydroelectricity generation" (EIA, 2016). China used to be a net coal exporter in the past, but high transportation costs across China that has made imports less expensive and higher demand growth have made the country a net coal importer from 2009. Moreover, lower international coal prices have contributed to make China a coal importer (EIA, 2016). According to EIA, imports have risen substantially from 2008, and total coal imports increased to around 327 million short meters in 2013, a 14% increase over 2012. In 2012, the 65% of China's imports came from Indonesia and Australia (EIA, 2016). According to EIA, in 2014 also imports started to decline due to slower economic growth and electricity demand, and excess domestic supply. Coal imports dropped by 11% in 2014 compared to the year before. In response to weaker demand many small mines in China have resulted unprofitable and closed. Larger and low-cost mines maintained a high production even though demand slowed down, to reach economies of scale, keep their cost low, and compete with international low prices (EIA, 2016).

At the end of 2014, China reformed the coal tax structure, and allowed local governments to collect between 2% to 10% of domestic coal sold. Moreover, all surcharges and fees related to coal production were abolished (EIA, 2016). In January 2016, the Chinese government has imposed restriction on coal imports and reintegrated import tariffs (EIA, 2016). According to EIA, through these tools Chinese government was able to protect domestic producers and decrease excess supply (EIA, 2016). Moreover, from 2014 the government has made huge investments in railway capacity, storage and coal processing facilities and electricity transmission capacity (EIA, 2016).

Coal industry is divided between large state-owned mines, local state-owned mines and town coal mines. China's largest state-owned coal companies (Shenhua Group and China National Coal Group) account for around 50% of total coal production, local state-owned for 20% and town mines for 30%. According to EIA, due to low coal price environment, small mines are going to close while the share of total production from large and more profitable state-owned companies is going to increase (EIA, 2016).

As opposite to the past, China is becoming more open to foreign investments in coal sector, due to increased willingness to improve safety and environmental problems related to coal mines, and to advance investments in coal-to-liquids, CBM production, coal-to-gas, and slurry pipeline transportation projects (EIA, 2016).

Nuclear

Nuclear power represents a small portion in the total power generation of the country. According to EIA, it amounted to 106 TWh in 2013, accounting for 2% of total power generation (EIA, 2016). China has suspended nuclear plants capacity installations after Fukushima nuclear accident in March 2011, in order to guarantee safer reviews of nuclear plants. Despite that, China promoted nuclear power as a green, efficient and reliable source of electricity generation, and after new plants and constructions were approved from the State Council at the end of 2012, new nuclear capacity highly increased. According to EIA, China added 23 GW of nuclear energy from 2013, and additional 23 GW power plants will be operational in 2019 (EIA, 2016).

Renewable Energy

Rapidly growing demand for energy and related greenhouse gas emissions have driven countries around the world to promote more sustainable development, energy planning and policy making to address climate change (IEA, 2015). According to IEA, the use of energy represents by far the largest source of emissions; energy sector accounted for two-thirds of total greenhouse gas emissions in 2013, and 80% of CO2 (IEA, 2015). Global CO_2 emissions amounted to 32.2 $GtCO_2$ in 2013 (IEA, 2015). At a regional level, China represented 28% of total emissions in 2013, leading the rank of top polluters worldwide (IEA, 2015). In particular, according to EIA, China has been highly relying on coal that is abundant in the country (EIA, 2016). As stated by IEA, coal is the most polluting energy source, and it contributed to 46% of total CO_2 emissions in 2013 (IEA, 2015). Despite coal is likely to remain the major energy source in China, attempts to reduce greenhouse emissions has been undertaken through strict environmental regulations on high-polluting industries and increasing development of renewable energy structures and technologies (EIA, 2016). According to IEA, China appears in the top countries for hydro, solar, wind and bio-energy production and electricity consumption, and it is one of the top renewable energy capacity installers in 2015 (IEA, 2016). Most recent bio, hydro, wind and solar power improvements in China according to REN21 (REN21, 2016) are discussed in this paragraph.

A program to encourage the production and use of bio-power in the heating sector was launched in China in 2008. It promoted the use of agricultural residues for heating in order to reduce coal use in local district heating schemes, stimulating the growth of a national bio-power market and industry. The policy provided support to farmers for the collection and procession of agricultural residues. According to REN21, 6 million tons of pellets, amounting to almost 96 petajoules (PJ) of energy content, were produced and used in China during 2015 (REN21, 2016). As regard transport sector, according to REN21, China is the third largest ethanol producer worldwide. In 2015, it produced around 2.8 billion liters of ethanol, even if this figure represented a decline of 14% with respect to the year before. The decline in ethanol production was due to official suspension of maize-based ethanol production (REN21, 2016). The country has increased ethanol imports during 2015 to provide for decreased domestic production, particularly from the United States (REN21, 2016). According to REN21, bio-power capacity in China amounted to 10.3 GW in 2015, an addition of 0.8 GW over 2014. Generation increased 16% with respect to 2014, to an estimated 48.3 TWh (REN21, 2016).

In 2015, China reconfirmed as the top country for hydropower capacity (REN21, 2016). According to REN21, as in the past several years, the most significant share of new hydropower capacity in 2015 was commissioned in China, which accounted for about one-half of the world total. Despite that, China’s hydropower additions amounted to 16 GW, showing a 26% decline over 2014. Moreover, global pumped storage capacity increased by 2.5 GW. Total installed capacity in 2015 totaled 296 GW plus 23 GW of pumped storage capacity (REN21, 2016). According to REN21, hydropower generation in China increased for the second consecutive year, totaling 1,126 TWh, 5% more than in 2014 (REN21, 2016). Despite China is investing in largescale projects (such as the 10.2 GW Wudongde plant, which is expected to be completed by 2020), and in smaller projects in more remote regions, some potential projects have not been confirmed because Chinese authorities have refused construction permits due to some untapped resources (REN21, 2016). According to REN21, the country is actively investing in hydropower-related projects around the world, particularly in Africa, South Asia and South America (REN21, 2016).

According to REN21, China was the top country in global solar PV installations for the third consecutive year in 2015. China's government believed that solar power would be able to address the county's pollution problems and continued to increase installation targets to raise renewable generation. In 2015, China added almost 15.2 GW for a total of 44 GW, becoming the top country for cumulative solar PV capacity, with about 19% of the global total (REN21, 2016). According to REN21, 86% of total capacity regarded large-scale power plants, and the remainder distributed among rooftop systems and other small-scale installations (REN21, 2016). The rapid increase in solar PV capacity has caused severe problems as grid congestion and interconnection delays since 2012. Curtailment problems has become arduous in 2015, especially in the northwest (REN21, 2016). To address the problem of insufficient grid capacity and issues related to curtailment, China has supported top solar-producing provinces to "prioritize transmission of renewable energy, build more transmission capacity and attract more energy-intensive industries to increase local consumption." (REN21, 2016, p.60). Moreover, according to REN21, by 2015 China accounted for about two-thirds of the global module production, and among leading module manufacturers were many Chinese companies (REN21, 2016). According to REN21, China was the leading country also in the solar heating and cooling sector in 2015. Cumulative capacity reached 309.4 GW_{th} in 2015, representing about 70% of global total capacity, with almost 30.45 GW_{th} additions over the year (REN21, 2016).

Finally, In 2015 China dominated the wind power sector, and was followed distantly by the United States, Germany, Brazil, and India (REN21, 2016). According to REN21, China totaled 145.36 GW (34.1%) of total installed capacity in 2015, and was responsible for most of new capacity additions (REN21, 2016). According to REN21, some difficulties arose in transmitting wind power from turbines to population centers and led to grid curtailment in 2015. To address the problem, Chinese government has encouraged investments in grid development and many companies have built wind farms in the county's east and south in order to set supply closer to demand and bypass long-distance transmission issues through better grid infrastructures (REN21, 2016).

Electricity

China has become the world's largest power generator from 2011, when it overcame the United States (EIA, 2016). According to EIA, to sustain rapid economic development, the country expanded its generation capacity and became the highest in the world; installed electricity capacity amounted to 1,260 GW in 2014 (EIA, 2016). EIA expects that installed capacity will double to meet rising demand by 2040, totaling 2,265 GW. The rapid electricity demand growth of the past decade has pushed China to increase country's generation capacity, particularly fossil fuel-fired one. According to EIA prospects, although coal will remain the primary source of electricity generation in China, a combination of nuclear, natural gas-fired and renewable sources capacity will be added to coal power plants to address environmental and pollution issues (EIA, 2016). In fact, according to EIA, China plans to replace some coal-generated power with nuclear, renewable and natural gas sources, to reduce greenhouse gas emissions and heavy air pollution. In 2013, coal accounted for 63% of the electricity mix in China, followed by hydropower with 22%, which is the country's key source of renewable energy generation, wind-power with 6%, natural gas with 4%, oil with 2%, solar with 1%, biomass with 1% and nuclear with 1% (EIA, 2016).

Until 2002, electricity sector in China has been controlled by the monopoly State Power Corporation (SPC). In 2002, Chinese government dismantled it into three separate units, which was respectively responsible for generation, transmission and services. Since the reform, electricity generation has been administered by five state-owned generation companies, which stand for almost half of total electricity generation in China (EIA, 2016). These companies are the China Huaneng Group, China Datang Corporation, China Huadian Corporation, China Guodian Corporation, and China Power Investment Corporation. Local-owned enterprises and independent power producers generate the remaining electricity in China (EIA, 2016). Electricity transmission and distribution is controlled by two new companies, the China Southern Power Grid Company and the State Grid Corporation of China. They administer the nation's seven power grids. Moreover, to support and facilitate enforcements and investments in electricity sector, China

established the State Electricity Regulatory Commission (SERC), which aims at alleviate power shortages, improve efficiency and straighten infrastructures (EIA, 2016).
Electricity prices in China are determined by the National Development and reform commission (NDRC). According to EIA, a first attempt to reform electricity prices took place in 2004, by linking electricity prices to fuel costs. This reform contributed to financial losses for electric generators during high-coal prices period in 2011, but low-coal prices in 2012 prompted the government to lower tariff rates on electricity sold by generators to the grid for coal-power plants (EIA, 2016). When reforms in natural gas pricing took place, electricity tariffs for gas-fired power plants were linked to natural gas prices (EIA, 2016). In 2013, NDRC doubled the surcharge for renewable energy use to encourage investments in "greener" sources of energy (EIA, 2016).

Energy market in China is a unique case. The country has undergone decades of rapid increasing demand and managed to rise capacity generation to meet consumption. Now China has to face problems related to the way it increased the supply of energy. In fact, China mostly relied on coal for the production of energy, causing high level of pollution and environmental problems. The government is prompting renewable energy resources for the generation of energy in order to address both environmental and pollution problems and fulfill the country's energy needs.

2.2. Concerns and conflicts

China needs huge and increasing quantities of energy to sustain and support economic growth and development. The country is striving to search for sources of energy able to guarantee economic growth and energy security in the future. In fact, China is investing in renewable energy capacity and in more efficient technologies able to extract energy resources from exploited or challenging plants (EIA, 2016). This rush for energy can led to conflicts and hostility with other countries searching for the same resources.

In particular, the East China Sea is estimated to host many oil and natural gas reserves, and is able to ensure greater independence to a country in need for energy as China (EIA, 2016). The South China Sea includes the Paracel Islands, the Spratly Islands, and other areas such as the Pratas Islands, theMacclesfield Bank and the Scarborough Shoal. Territorial disputes in the East China Sea between China and Japan have led to tensions and disagreements. Long negotiations between the two parties resulted in an agreement in 2008, but both countries have continued unilateral actions in order to develop and assert sovereignty over the field (EIA, 2016). In fact, the agreement unraveled in 2009 and successively divergences over the contested area and ownership of the plants emerged again (EIA, 2016). Despite the Declaration of Conduct that the Association of Southeast Asian Nations (ASEAN) members have signed in 2002, all attempts to encourage members to cooperate in the exploration of resources in the area was vain, even because no regulations was established (EIA, 2016). The two sides agreed to improve relations and calm tensions in 2014 but territorial disagreements continued between countries bordering the South China Sea (EIA, 2016). China used a nine-dash line demarcate each country's maritime borders and relative resources. The willingness to gain control over valuable resources has aggravated relationships and caused tensions between China and the Philippines, and China and Vietnam too. According to EIA, China has increased its naval activity in the disputed area. The country also invaded Vietnam's exclusive nautical economic zone and placed an oil ring in the contested area for two months, which claimed be for exploration purposes (EIA, 2016).

According to EIA, current China's policy is to establish partnerships with other countries bordering the South China Sea in order to explore the area and develop resources in the sea (EIA, 2016).

Conflicts and tensions between countries are not the only problems caused by rapidly growing need for energy. Unregulated production and consumption of energy and related greenhouse gas emissions have caused severe environmental problems and have driven countries around the world to promote more sustainable development, energy planning and policy making to address climate change (IEA, 2015). According to IEA, the use of energy represents by far the largest source of emissions; energy sector accounted for two-thirds of total greenhouse gas emissions in 2013, and 80% of CO2 (IEA, 2015). Global CO_2 emissions amounted to 32.2 $GtCO_2$ in 2013 (IEA, 2015). At a regional level, China represented 28% of total emissions in 2013, leading the rank of top polluters worldwide (IEA, 2015). In particular, according to EIA, China has been highly relying on coal that is abundant in the country (EIA, 2016). As stated by IEA, coal is the most polluting energy source, and it contributed to 46% of total CO_2 emissions in 2013 (IEA, 2015). Despite coal is likely to remain the major energy source in China, attempts to reduce greenhouse emissions has been undertaken through strict environmental regulations on high-polluting industries and increasing development of renewable energy structures and technologies (EIA, 2016).

Moreover, some battles between environmentalists and hydropower firms have taken place in China for decades. In fact, according to the New York Times, on all the rivers in China have been build dams to generate hydropower, with one single exception in southwest China, where the Salween river is the last free-flowing river in China. Environmentalists have tried to protect the last wild river and have fought very fiercely also creating disagreements between them and people thinking that China should use all the resources it has to reduce pollution and minimize climate change. The construction of dams on the Salween river would mean that tens thousands of people would be forced to move from their homes, farmers and fishermen would lose their job and the river's biodiversity would be irremediably affected by the construction of the dams. This specific river is home to many different ethnic and religious communities and has a big role in carrying on peculiar traditions and jobs that nowhere else can be found. These traditions are unique but involve the presence of the river in its wild form, because the construction of dams will completely destroy and inundate these communities. Moreover, people moving from their homes not always receive the right compensation for their loss, and those who receive it usually wait long time after they have left their homes. For these reasons, many dam projects have been scrapped and many construction sites abandoned, but now other five dams that would contribute to 350 gigawatts of hydropower capacity have been proposed, and residents are afraid that construction could be resumed. People are aware that China should do whatever it can to fight global warming, but citizens think that it should be done while thinking to their benefits too (New York Times, June 18, 2016).

2.3. Policy support

China has been striving to restructure its industries and steer the economy onto a sustainable path. Indeed, it has cut greenhouse gas emissions, improved energy structure and slashed pollutant industrial capacity (IEA, 2015).

Over the past 15 years, the Chinese government has implemented a series of important reforms in the power sector that have improved the availability of electricity and improved the efficiency, reliability, and environmental performance of the sector (IEA, 2015). The Chinese government has achieved ambitious energy and environmental goals in the 12th Five-Year Plan (2011–2015), and the new Air Pollution Prevention and Control Action Plan (2013–2017) and it has planned other driving objectives in the 13th Five-Year Plan (2016-2020) (IEA, 2016).

China's Five-Years Plans (later re-called guidelines) are a series of social and economic development activities. In these plans, strategies and growth targets are established in order to "green" the economy. In particular, the 12th Five-Year Plan (2011–2015) achieved a coal consumption reduction of 2.9 % in 2014 and clean energy (including hydropower, nuclear power, wind power and natural gas) accounted for 16.9 % of energy consumption by 2014 (IEA, 2016). The 13th Five-Year Plan (2016-2020) aims at developing environmental technology industry, ecological living and culture. Addressing these challenges and meeting these goals will require policies that reshape the power sector (IEA, 2015).

Important renewable policies enacted in China comprehend the Renewable Energy Law, the Document 625, the Revised Air Law, The US-China Joint Presidential Statement on Climate Change and the Paris climate conference.

The first Renewable Energy Law was adopted in China at the 14th Session of the standing committee of the 10th National People's Congress on February 28, 2005. The law aims "to promote the development and utilization of renewable energy, improve energy structures, safeguard energy security, protect the environment and realize the sustainable development of the economy and society" (Renewable Energy Law, ch.1, Art.1, 2005). With "Renewable energy" the law refers to "non-fossil energy of wind energy, solar energy, water energy, biomass energy, geothermal energy and ocean energy" (Renewable Energy Law, ch.1, Art.2, 2005). It requires that "grid companies shall buy all the grid-connected power produced with renewable energy" (Renewable Energy Law, ch.2, Art. 14, 2005). Moreover, the government supports and encourages "the construction of independent renewable power systems in areas not covered by the power grid, and the installation and use of renewable energy systems in workplaces and in private houses" (Renewable Energy Law, ch.2, Art.15-17, 2005). Energy authorities of the State Council set medium and long-term targets for total capacity development and renewable energy use to comply with at national level. Targets were set according to national demand of energy and actual situation of renewable energy resources. Based on that target, they prepared national renewable energy development and utilization plan (Renewable Energy Law, ch.1, Art.8, 2005).

On March 24, 2016, the Chinese government issued a major policy announcement on renewable energy, known as Document 625. The aim of Document 625 is to guarantee that grid companies purchase output from renewable generators. It introduces new elements with respect to the original Renewable Energy Law enacted in 2005, which had not been so successful because of the constant high level of curtailment of energy from wind, solar, hydro and other renewable resources. Curtailment is a reduction in the output of a generator from what it could otherwise produce given available resources, it can also result in renewable energy plants generating less than what they could potentially produce. This reduction of the operations is done in order to give the company the means (and time) to achieve financial and operational stability. Chinese government is trying to use as much clean energy as it can and curtailment represent an expensive phenomenon, both in terms of money and health. Document 625 states compensations for renewable energy generators for curtailment. Under the Original Renewable Energy law, renewable energy generators have not received payment for the hours that they were curtailed. According to Document 625, curtailment costs will be paid by conventional generators, with some exceptions. The Regulatory Assistance Project (RAP) in China has issued a report in 2013 in which they discuss recommendations for curtailment compensation (Recommendations for Power Sector Policy in China, 2013). In particular, these recommendations recommend: defining compensation arrangements to encourage more flexibility from existing generators, prioritizing flexibility when considering and approving new generation plants, stopping addition of inflexible generation, better analyzing generation options, improving coordination of power sector planning with environmental policy design and implementation, adopting generation interconnection and transmission planning practices, and implementing priority dispatch for renewables (RAP, 2013).

Anyway, policymakers have encountered many difficulties thus far in ensuring priority for renewable energy generation, and the enforcement of these new payments will probably be a significant challenge.

Moreover, Document 625 stipulates that renewable generators are allowed to compete in the mid-long term trading and spot market and to negotiate contracts with end-users. Furthermore, priority will be given to renewable generators in the stipulation of contracts with end-users and their priority dispatch status will permit them to pay no fee to other types of generators or grid companies.

The revised Air Law, issued by the National People's Congress (NPC) in August 2015 and effective from January 2016, aims at improving the condition of air pollution that has plagued many Chinese cities and regions. It requires "priority status to clean energy in electricity dispatch" (The revised Air Law, Art.42, 2015). In fact, according to the revised Air Law, given the severe condition of air pollution in China and the contribution that electricity generation gives to air pollution, fundamental energy policies should be committed to air quality. The law promotes the use and production of clean energy, a more efficient use of coal in the production of energy and the adoption of technologies to control air pollution emissions in exiting coal power plants in order to reduce air pollution (The revised Air Law, art.32, 2015).

The US-China Joint Presidential Statement on Climate Change, issued in September 2015 and reaffirmed in March 2016, aims at a green dispatch system creation in order to prioritize power generation from renewable sources and accept electricity especially from the most efficient and less-polluting energy generators. In September 2015, the leaders of the two countries met in Washington and announced their ambitious climate actions including major domestic policies and cooperative measures. China and United States are the most polluting nations in the world, and both have undertaken severe measures to build green, low-carbon and environmental friendly economies to combat climate change. At the Paris Agreement in December 2015, the two countries played a critical role in designing the climate change agreement and encouraged other parties to join the agreement in order to bring the Paris Agreement into force as soon as possible. United States and China made also bilateral and multilateral commitments with other countries to achieve other successful outcomes and accelerate clean energy innovation and deployment. These initiatives were fulfilled through the US-China Climate Change Working Group and Clean Energy Research Center.

On December 2015, at the Paris climate conference (COP21), China and other 194 countries adopted the first legally binding global climate deal. The agreement will enter into force in 2020 and aims to reduce emissions, decrease global average temperature by 2° (compared to pre-industrial times) and minimize the negative effects of climate change. Governments agreed to cooperate and pursue transparency and, in order to achieve these goals to meet every 5 years and share results and set other targets. The use of more efficient and less polluting energy, green transportation, sustainable architecture, more efficient land use and agriculture are set to be the tools with which targets will be meet.

A process of transition from fossil-based to clean energy generation is under way and is supported by new technologies development, focused policy support and international consensus. Investments, energy related laws and agreements are increasing around the world and in China. In particular, considering the severe condition of air pollution in China's urban areas and the huge contribution that the country is giving to greenhouse emissions and climate change, China is especially prompted to fight against environmental issues with any available tool.

3. Review of literature

There are several existing studies that analyzed the relationship between economic growth and energy, but little literature on the relationship between renewable energy and economic growth. Moreover, despite the importance of both renewable energy and economic growth in China, there exist little literature on the relationship between these variables because China’s implementation of renewable energy sources is relatively recent, and data has been limited. This chapter firstly reviews the literature pertaining the relationship between energy and GDP, secondly the restricted one pertaining to renewable energy and GDP and finally a review of the Environmental Kuznet’s Curve (EKC), which appeared to be of particular interest if linked to China.

In previous studies, Kraft and Kraft (1978) found a uni-directional relationship between GNP and energy. They used a time-series data from 1947-1974 for the USA. Many other studies followed this one, which employed panel data for different countries. Among these studies there were Akarca and Long II (1980), Abosedra and Baghestani (1991), Masih and Masih (1997), Soytas and Sari (2003) and Chiang (2005).

Other studies such as Glasure (2002), Erdal et al. (2008), Belloumi (2009) and Mathur et al. (2015) supported bi-directional causality between energy and GDP growth instead. Dalei (2016) found a non-linear sigmoid relation between energy consumption and GDP. In fact, according to this study, at the beginning energy consumption increases at an increasing rate, together with GDP. At a certain point in time, energy consumption starts to increase at a decreasing rate, while GDP continues to rise. The study explains that the main reason for which the relation is overturned is the use of renewable resources in place of conventional ones.

Sadorsky (2009) estimates the relationship between economic development per capita and renewable energy consumption per capita for 18 emerging economies using a time series-data from 1994-2003. The results show that in emerging economies a 1% increase in real GDP per capita rises renewable energy consumption between 3.39% and 3.45 % per capita. Leuschner and Paige (2014) estimates the effect of GDP per capita on renewable energy production in China. They used hydropower as a representative of renewable energy since it represents a relevant source in China and found that a 10% increase in GDP per capita causes a 0.875 percentage point increase in hydropower production.

The Environmental Kuznet's Curve (EKC) gives support to the relationship between GDP and renewable energy consumption. According to this concept, there exist a non-linear relationship between economic growth and pollution, because as people become wealthier, it cares more about health and wants to decrease the level of pollution. Thus, as economic growth increases the level of pollution decreases. This concept is particularly important in a country such as China, where fast economic growth has taken place since the 1980s and the level of pollution has become severe in the last few years (IEA, 2016). It can be supposed that a more intensive use of renewable energies help decreasing the level of pollution. Jalil et al. (2009) and Song et al. (2008) investigated on the existence of the EKC in China. They used different representatives of pollution but both obtained that the non-linear relationship between economic growth and pollution holds in China in the long run. In fact, pollution represents a major problem in China, and the government is trying to reduce and minimize it through renewable energy deployment. According to Ying et al. (2007), despite increasing economic growth, carbon emissions produced per unit of GDP has been decreasing due to improved energy efficiency and renewable energy deployment. This shows that fuel switching from conventional to renewable energy of more recent years is able to decrease environmental impact. Renewable energy deployment gives the opportunity for positive effects on decreasing CO2 emissions.

The International Renewable Energy Agency (IRENA, 2016) provides quantitative evidence of the impact that renewable energy has on GDP at global level. It shows that doubling the share of renewables used in the global energy mix increases GDP between 0.6% and 1.1% by 2030. The increase accounts between $706 billion and $1.3 trillion. The magnitude of the impact depends on the country considered. Fossil fuels exporting countries would show a decline in their GDP following an increase of the use of renewables, while other countries would benefit from renewables deployment.

This study analyzes the impact of renewable energy consumption per capita on China's GDP per capita. It analyzes the research questions of Sadorsky (2009) and Leuschner and Paige (2014) from a different perspective. Instead of analyzing the impact of the increase(or decrease) in GDP on renewable energy production, it analyzes the effect of renewable energy consumption over GDP in China.

4. Empirical Model

The availability of secondary data on energy statistics and macroeconomics indicators is restricted to past 43 years. Further, data on some variables that are incorporated in the empirical model is not readily available. Regarding the methodology, the Instrumental Variable Regression approach is used to assess the impact of Renewable Energy consumption on the Nation's Gross Domestic Product. The instrumental variable method makes it credible to assert that the observed association is a causal relationship rather than simply a correlation (Key and McBride, 2007).

4.1. Data

Secondary data on Energy Statistics is obtained from International databases such as World Bank Database while local databases of the Ministry of China are also approached for macro-level statistics. To empirically test the impact of renewable energy consumption on the GDP, yearly data is taken for the period from 1971 to 2013. The data obtained can be divided into three categories – Energy Statistics, Financial Indicators and Macro-economic Indicators.

To identify the energy indicators for renewable energy, yearly data on renewable energy consumption is obtained from the World Bank Database. Further, the oil price, gas price and coal price is obtained from the International Energy Statistics Database. Table 1 provides the summary statistics of Energy Indicators.

Table 4.1: Summary statistics of Energy Indicators

Variable	Observation	Mean	Maximum	Minimum	Std.Dev
Renewable Energy	43	0.0009473	0.0022171	0.0004649	0.0004805
Oil Price	43	29.11093	96.29	1.7	22.67917
Gas Price	43	2.58119	7.97	0.18	1.92032
Coal Price	43	21.21714	36.91	6.34	6.649572
Energy Efficiency	43	6.748917	7.7080832	6.141894	0.4356522

Sources: World Bank Database and International Energy Statistics Database.

The second important classification is done with regards to the inclusion of Macroeconomic variables. The main variables of the study are Gross Domestic Product, Gross National Income and Gross Capital Formation. The data for these variables was collected through the World Bank database.

Table 4.2: Summary statistics of Macroeconomic Indicators

Variable (In log)	Observation	Mean	Maximum	Minimum	Std.Dev
Gross Domestic Product	43	6.335938	8.852501	4.7673725	1.201031
Gross National Income	43	6.359576	8.811355	4.787492	1.143404
Gross Capital Formation	43	6.924169	9.935675	4.519304	1.765053

Source: Author's elaboration.

The last category is represented by the Financial Indicators. Financial Indicators are included to capture the effect of public funding and private investments on renewables.

Table 4.3: Summary statistics of Financial Variables

Variable	Observation	Mean	Maximum	Minimum	Std.Dev
Liquid Liability	43	35	16.15732	11.84195	1.307043

Source: Author's elaboration.

4.2. Methodology

This study applies a rigorous econometric model to understand the relationship between renewable energy and Chinese GDP. The Instrumental Regression method is followed. The dependent variable chosen is Growth Per Capita while the explanatory variables are energy efficiency and gross capital formation. This section is divided into three sub-sections. In the first sub-section, the theory of Instrumental Variable Regression is presented. Next, the methodology behind creating the indices is explained. In the last two sections, co-integration analysis and the Error Correction Model are explained.

Instrumental Variables

The Instrumental Variable (IV) approach is used when the BLUE assumptions of OLS regressions do not hold true since the OLS prediction stands inconsistent as the explanatory variable and error term are correlated. To eliminate this error correlation, Instrumental Variable regression methodology is applied. Before proceeding to understand the mathematics behind this, some important terminologies are explained. Variables that are correlated with the error term are called Endogenous Variables while the variables that are uncorrelated with the error term are called Exogenous Variables. A valid instrumental variable must satisfy two conditions. Firstly, it has to be relevant. If an instrument is relevant, then it is correlated with the regressor. Secondly, it has to be exogenous i.e. it has to be uncorrelated with the error term.

IV regressions consider a dependent variable Y, an independent variable X and the error term u. From these premises, two cases can arise. X and u are uncorrelated while Y is correlated with u, then the OLS is consistent, or X and u are correlated, then the OLS estimator is inconsistent because of u's indirect effect on y through x. IV regressions introduce the instrument Z. If Z is correlated with X but not with u then the estimator is consistent. Moreover, Z has an indirect effect on Y through X similar to u.

Mathematically, the population regression model relating the dependent variable with the explanatory variables is

$$Y_i = \beta_i X_i + u_i$$

Then, the OLS estimator is

$$\beta_{ols} = \beta + (X'u)\ X'X \text{ when X and u are uncorrelated}$$

$$\beta_{ols} = \text{Bias} + (X'u)\ X'X \text{ when X and u are correlated}$$

If they are correlated then an additional 'instrument' variable, Z, is used to separate the correlated part with the uncorrelated part.

$$X = \alpha Z + v_i$$

The computation for the IV-2SLS is presented as follows:

<u>First Stage:</u> Regress each X on Z and save the predicted values

$$\alpha = (Z'Z)^{-1}Z'X$$

$$X = Z\alpha = Z\ (Z'Z)^{-1}Z'X = P_zX$$

<u>Second Stage:</u> Regress Y on the predicted values from the first stage

$$Y = X\beta + u_i$$

$$\beta_{2SLS} = (X'P_zX)^{-1}\ X'P_zY$$

The validity of the instruments can be asserted by reasoning they are relevant instrument and exogenous. In other words, the correlation between the instruments and the explanatory variable is non-zero and the error terms and instruments are not correlated.

$$\text{Corr}\ (Z_i, X_i) \neq 0$$

$$\text{Corr}\ (Z_i, u_i) = 0$$

The parameters are exactly identified if the number of endogenous variables is equal to the number of instruments. If the number of endogenous variables exceeds (less) the instruments, then it is a case of over-identification (under-identification).

In this study, the Instrumental Variables Two Stage Least Squares (IV-2SLS) methodology is approached. The following variables are of concern

Dependent variable – GDP, Growth Per Capita
Exogenous Variable 2 – GCF, Gross Capital Formation
Exogenous Variable 3 – EC, Energy Efficiency
Instrumented Variable – RE, Renewable Energy Consumption
Endogenous Variable 1 – OP, Oil Price
Endogenous Variable 2 – GP, Gas Price
Endogenous Variable 3 – CP, Coal Price
Endogenous Variable 4 – L, Liquid Liability

In a simultaneous-equations framework, we could write the model we just fit above as

$$RE_i = \pi_0 + \pi_1\, OP_i + \pi_2\, GP_i + \pi_3\, CP_i + \pi_4\, L_i + v_i$$
$$GDP_i = \pi_0 + \pi_1\, EC_i + \pi_2\, GCF_i + \pi_3\, RE_i + u_i$$

In the first stage, the energy intensity variables are used as instruments for renewable energy consumption, controlling for Energy Efficiency and Gross Capital Formation.

(1) $$RE_i = a_i\, OP_i + b_i\, CP_i + c_i\, GP_i + d_i\, EC_i + e_i\, GCF_i + f_i\, L_i + g_i\, EC_i + v_i$$

As emphasized by Angrist and Krueger (2001), in two-stage least squares, consistency of the second-stage estimates does not depend on using the correct first-stage functional form (Kelejian, 1971). Recall, Z_i is exogenous i.e. the variables OP_i, CP_i, GP_i and L_i are uncorrelated with u_i, the error term of the main regression equation. The other component of the regression equation (1) is the error term v_i, which is correlated with u_i.

$$E\,(u_i \mid OP_i, GP_i, CP_i, L_i) = 0$$

The second stage regression estimates the impact of renewable energy consumption on GDP per capita.

(2) $$GDP_i = \alpha + \beta_1 GCFi + \beta_2 ECi + \beta_3 RE_i + u_i$$

The two stage least squares is the default method for regressing over-identified models. However, two other methods are also widely used. The first is the Generalized Method of Moments (GMM). In this method, different weights are assumed for the variables in the covariance ratio. The other common method is the Limited Information Maximum Likelihood (LIML). In studies where the sample size is small, this estimator proves to be more efficient.

The IV regression techniques does pose certain limitations. Firstly, it is based on common sense and intuition. It is not possible to show that the correlation between the instrument and the error term is zero. One has to use his common sense to decide if it makes sense to consider such an instrument. However, the existence of correlation between the instrument and the regressor can be easily tested from the First-Stage regressions. Lastly, an instrument could also be weak and in such a case the results of the IV regression would not differ much from the OLS regressions.
Past studies have shown that renewable energy consumption has a significant impact on GDP per capita. This has been studied in chapter 3 with a thorough review of the literature. The instrumental variables regression model to evaluate the effects of renewable energy on GDP have been explored in the methodology section of chapter 4.

The following hypothesis were tested.

Table 4.4: Hypothesis

SN	Hypothesis	Variable	Method of Testing
1	Higher the renewable energy consumption, higher is the gross domestic product.	RE	Instrumental Variable Regression
2	Higher the energy efficiency, lower is the gross domestic product	EC	Instrumental Variable Regression
3	Higher the gross capital formation, higher is the gross domestic product.	GCF	Instrumental Variable Regression

Source: Author's elaboration.

Co-integration

Co-integration analysis is performed to check for the long-run equilibrium relationship between renewable energy consumption and gross domestic product. The variables considered in the study are found to be unit root processes or they are integrated of order 1. Therefore, it is rational to proceed with the co-integration analysis since two or more variables integrated of order 1 can be expected to obey a long run relationship. In other words, if two variables are I (1) then their linear combination is said to be integrated of order 0. One of the most common tests performed to check for co-integration is the test used in this study, the Johansen test. It is especially used when there are large samples of study. Another common method to check for co-integration, is the Engle Granger two step procedure. It is explained as follow:

If x_t and y_t are non-stationary and integrated of order 1 then, their linear combination is stationary.

$$x_t \sim I(1) \text{ and } y_t \sim I(1)$$

$$\text{then, } y_t - \beta x_t = \mu_t$$

$$\text{i.e., } y_t - \beta x_t = I(0)$$

The advantage of the Johansen test over Engle-Granger two-step procedure lies in the fact that the former can detect multiple long run stationary relationships among the non-stationary variables if there are any.

Error Correction Model

Two or more variables said to be co-integrated belong to a particular time series model through which the long run stochastic trend can be analyzed. This set of model is called the error correction model, which helps to predict the short term and long term effects of one time series on the other.

We can start with a simple model where two variables have a long run equilibrium relationship.

$$Y_t = kX_t$$

In the logarithmic form,

$$y_t = k + x_t$$

The dynamic relationship can be further written as :

$$y_t = \beta_0 + \beta_1 x_t + \beta_2 x_{t-1} + \alpha_1 y_{t-1} + u_t$$

In the long run,

$$y_t = y_{t-1} = y^*$$

$$xt = x_{t-1} = x^*$$

Thus we get,

$$y^* = \beta_0 + \beta_1 x^* + \beta_2 x^* + \alpha_1 y^*$$

$$\text{or } y^* = \beta_0 / (1- \alpha_1) + \{\beta_1 + \beta_2\}\{x^*\} / (1- \alpha_1)$$

$$\text{So we have, } \{\beta_1 + \beta_2\} = (1- \alpha_1)$$

Or

$$y_t = \beta_0 + \beta_1 x_t + (\pi - \beta_1)\, x_{t-1} + (1- \pi)\, y_{t-1} + u_t$$

$$y_t - y_{t-1} = \beta_0 + \beta_1 (x_t - x_{t-1}) + \pi (x_{t-1} - y_{t-1}) + u_t$$

So finally, we have the error correction model,

$$\boldsymbol{\Delta y_t = \beta_0 + \beta_1 \Delta x_t + \pi (x_{t-1} - y_{t-1}) + u_t}$$

Here the first term in the right hand side of the equation explains the general dynamics of the co-integrating equation. The constant, $\boldsymbol{\beta_0}$, is called the long run coefficient of the vector error correction model (VECM). It explains how fast (or slow) will the equation converge to equilibrium. The second term in the equation shows the short run dynamics between the two variables. In other words, it explains the impact of a unit change in the explanatory variable on the dependent variable. The third term is the most important term in this equation. It is known as the ECT or Error Correction Term. Here, the change in one variable is related to the change in dependent variable as well as the gap between the variables in the previous period.

5. Results

This chapter presents the results of regression analysis performed using the statistical software STATA to analyze the impact of renewable energy consumption per capita over GDP per capita in China.

5.1. Augmented Dickey Fuller Test

This test is performed in order to check for stationarity of the variables.

Table 5.1: Augmented Dickey Fuller Test

Variable	Characteristic
Log of GDP Per Capita	I(1)
Log of Gross Capital Formation Per Capita	I(1)
Log of Renewable Energy Per Capita	I(1)
Log of Energy Efficiency	I(1)
Log of Oil Price	I(1)
Log of Coal Price	I(1)
Log of Gasoline Price	I(1)
Log of Liquid Liabilities	I(1)

Source Author's elaboration

The data summarized in the chapter before is first tested for stationarity. This is done for two reasons. Firstly, to avoid spurious regressions and secondly, to achieve significant t-statistics. In order to validate the hypothesis testing, the unit root tests are performed. Incidentally, most of the variables were found to be non-stationary. Therefore, the variables were transformed by taking their first difference to achieve a stationary dataset. The augmented dickey fuller test, shown in table 5.1, was applied to obtain the error corrected model.

As seen from table 5.1, all the variables are integrated of order 1. This is a great fit for the model, especially for applying cointegration analysis and error correction model.

5.2. Instrumental Variables Regression

Instrumental Variables (IV) Regression of the equation is run with renewable energy consumption per capita as the endogenous variable.

Table 5.2 : IV regression

	dgdp
dre	1,714.805
	(2.25)*
dgcf	0.275
	(1.51)
dlec	-1.914
	(1.75)
_cons	0.054
	(1.89)
R^2	0.18
N	34

* *p*<0.05; ** *p*<0.01

The IV regression was approached as described in the previous chapter. As evident from the table 5.2, renewable energy consumption and gross capital formation have a positive effect on the GDP per capita. On the other hand, energy efficiency has a negative impact on the GDP per capita. This is in accordance with the hypothesis put forward in the previous section.

A 1% increase in the renewable energy consumption would lead to a 1,714% increase in the GDP per capita. This indicates that renewable energy consumption is likely to impact GDP per capita in a tremendous way, especially after the threat of climate change which is causing China to turn to more renewable energy sources. It is important to note that renewable energy consumption is considered as an endogenous variable here. As described in the model, renewable energy consumption is a function of oil price, coal price, gas price and the financial institutions. An implication of this would be that oil price, coal price and gas price have a negative impact on renewable energy consumption as an decrease in their price would attract more consumption which would in turn cause renewable energy consumption to decrease. Another important aspect is the importance of financial institutions. Financial institutions can make it feasible for the government to produce low cost renewable energy. Given the fact that oil, coal and natural gas are non-renewable energy sources, the renewable energy consumption is likely to experience an increasing trend in the long term.

Gross capital formation is shown to positively affect GDP per capita. A 1% increase in the GCF would increase the GDP per capita by 0.275 units. This is again significant since Gross Capital Formation is known to be a major determinant of Economic growth, theoretically.

Lastly, the impact of energy efficiency on the GDP per capita is analyzed. According to the literature, if a country is energy efficient it is supposed to positively affect GDP per capita. However, this case represent a paradox as energy efficiency is shown to negatively affect GDP per capita. A 1% increase in the energy efficiency would mean a 1.9% decrease in the GDP per capita.

Following the IV regressions, two tests are performed to check for validity of the instruments. Firstly, the Durbin Wu-Hausman test is performed for endogeneity. The null hypothesis for the DWH test is that variables are exogenous.

Table 5.3: Durbin Wu-Hausman Test

Test	**Statistic**	**Prob > F**
Durbin Score	3.62375	0.05
Wu-Hausman	3.46481	0.07

Source Author's elaboration

The probability score is 5% and 7% respectively which is less than 5% at the 95% level of confidence and 10% at the 90% confidence level. Therefore, we can reject the null hypothesis of exogenous variable. In other words, the chosen endogenous variable is valid.

The difference between the Durbin and Wu–Hausman tests of endogeneity is that the former uses an estimate of the error term's variance based on the model assuming the variables being tested are exogenous, while the latter uses an estimate of the error variance based on the model assuming the variables being tested are endogenous. Under the null hypothesis that the variables being tested are exogenous, both estimates of the error variance are consistent (Stata Manual, 2013). Therefore, we could continue to treat renewable energy consumption as endogenous.

Table 5.4: Sargan Test of Overidentification

Test	**Statistic**	**Prob > F**
Score chisquare (3)	2.33777	0.5053

Source author's elaboration

Table 5.4 shows that the probability score is 50% which is greater than 5% at the 95% level of confidence. Therefore, we cannot reject the null hypothesis of over identifying restrictions are valid. In other words, the chosen endogenous variable is valid.

Table 5.5: Shea's Partial R^2

*Variable	R-Sq	Adjusted R-Sq	Partial R-Sq	Robust F(4,40)	Prob > F
Renewable Energy Consumption	0.8374	0.8012	0.3967	4.43803	0.0069

Source author's elaboration

Minimum Eigen Value Statistic – 4.43803

The R-squared and Adjusted R-square statistics could be misleading because it could happen that the instrumented variable could be strongly correlated with the exogenous variables but weakly correlated with the included instruments. Therefore, the partial R-squared statistic is measured. It measures the correlation between productivity and the additional instruments after partialling out the effect of the exogenous variables. In this case the partial R-squared statistic is 0.8374 which explains that the instruments exhibit a 84% variation in the first regression model. Further, the F statistic is significant since the Prob > F value is less than 5%. Therefore, the instruments jointly explain the endogenous regressor. Lastly, the Cragg and Donald (1993) minimum Eigen value statistic is 4.438. Stock and Yogo (2005) tabulated critical values of 5%, 10%, 20% and 30% models. Unfortunately, the F statistic of 4.43 does not exceed the critical values and hence we cannot reject the null hypothesis of weak instruments.

5.3. Cointegrating Equation

The Johansen test is carried out to check for the existence of cointegrating equation and the rank.

Table 5.6: Johansen tests for cointegration

```
. vecrank dgdp dre dgcf dlec, trend(constant) lags(3)

                     Johansen tests for cointegration
Trend: constant                                         Number of obs =      39
Sample:  1975 - 2013                                             Lags =       3
```

maximum rank	parms	LL	eigenvalue	trace statistic	5% critical value
0	36	523.94912	.	50.2113	47.21
1	43	537.2925	0.49554	23.5245*	29.68
2	48	544.12554	0.29560	9.8585	15.41
3	51	548.6532	0.20720	0.8031	3.76
4	52	549.05476	0.02038		

Source STATA

To test for co-integration, firstly, the variables must be non-stationary at the level but stationary after first difference. As seen in our model, all the variables are found to be non-stationary (See Augmented Dickey Fuller test in table 5.1) and after taking their first difference, they are integrated of order (0) and hence stationary. The Johansen tests for co-integration is performed, the results of which are presented in the table above. The test assumes null hypothesis to be that there is no co-integration among the variables which is represented by maximum rank of 0 in the test report. The alternative hypothesis is that co-integration is present among the chosen variables.

The STATA test report of the Johansen co-integration test indicates the presence of co-integration among the variables. The trace statistic at rank 0 is 50.2113 which is greater than the critical value of 47.21. Hence, we can reject the null hypothesis and accept the alternative hypothesis. The trace statistic is 23.5245 which is less than the critical value of 29.68 and hence the Null Hypothesis cannot be rejected at the maximum rank 1. Therefore, it is clear that the variables are co integrated of order 0 and have a maximum rank of 1. One of the striking features of the Johansen co-integration test is that it allows to proceed with the Vector Error Correction Model once co-integration is established. The next section of this chapter runs the VECM model and analyses its results.

5.4. The Vector Error Correction Model

The VECM Model, as specified in the previous chapter, is run to check for the long run and short run causality of the model and the results are analyzed in the following pages. It is important to understand that the VECM is run only when co-integration among the variables is established. This has been duly showed in the previous section of this chapter. The results of the VECM model usually indicate three areas – Error Correction Term, Long Run causality and Short Run Causality. The three areas are further analyzed in this chapter.

Table 5.7: VECM

D_dgdp	L._ce1	-0.814
		(3.37)**
	LD.dgdp	0.016
		(0.07)
	L2D.dgdp	0.040
		(0.26)
	LD.dre	-2,577.871
		(2.92)**
	L2D.dre	-3,888.851
		(3.26)**
	LD.dlec	2.858
		(2.96)**
	L2D.dlec	4.517
		(4.04)**
	LD.dgcf	-0.187
		(1.10)
	L2D.dgcf	-0.006
		(0.04)
	_cons	-0.001
		(0.06)

Source STATA

a) Error Correction Term:

The error correction term is shown to have negative sign. This indicates there is a long run causality running from the explanatory variables to dependent variable, GDP. The standard error is 3.37, which is significant at the 1% level and hence the results are satisfactory.

b) Long Run Causality:

The error correction term rightly shows the presence of a long run causality from the explanatory variables to the dependent variable, GDP.

c) Short Run Causality:

As seen from the table below, there is no short run causality extending from GDP to its own lagged form. This is shown to be true through the insignificant nature of the standard errors. However, it is true that there is a short run causality extending from renewable energy and energy efficiency to the GDP.

Table 5.8: VECM

D_dre	L._ce1	0.000
		(1.18)
	LD.dgdp	-0.000
		(1.29)
	L2D.dgdp	-0.000
		(1.56)
	LD.dre	-0.049
		(0.09)
	L2D.dre	-0.099
		(0.14)
	LD.dlec	-0.000
		(0.28)
	L2D.dlec	-0.000
		(0.08)
	LD.dgcf	0.000
		(0.33)
	L2D.dgcf	0.000

		(1.36)
	_cons	0.000
		(0.82)

Source STATA

a) Error Correction Term:

The error correction term is shown to have positive sign. This indicates that long run causality is not present from the explanatory variables to dependent variable, GDP. The standard error is 1.18, which is not significant at the 1% or 5% level.

b) Long Run Causality:

The error correction term does not indicate a long run causality extending from explanatory variables to the dependent variable.

c) Short Run Causality:

As seen from the table below, there is no short run causality extending from any of the variables to GDP since they are insignificant.

Table 5.9: VECM

D_dlec	L._ce1	-0.048
		(0.39)
	LD.dgdp	-0.026
		(0.23)
	L2D.dgdp	-0.042
		(0.54)
	LD.dre	-265.871
		(0.59)
	L2D.dre	-368.076
		(0.61)
	LD.dlec	-0.110
		(0.22)
	L2D.dlec	0.014
		(0.02)
	LD.dgcf	-0.012

		(0.14)
	L2D.dgcf	0.129
		(1.70)
	_cons	0.002
		(0.35)

Source STATA

<u>a) Error Correction Term:</u>

The error correction term is shown to have negative sign. Furthermore, the error correction term is not significant and hence there is no presence of long run causality from the explanatory variables to dependent variable, GDP. The standard error is 0.39, which is not significant at the 1% or 5% level.

<u>b) Long Run Causality:</u>

The error correction term does not indicate a long run causality extending from explanatory variables to the dependent variable.

<u>c) Short Run Causality:</u>

As seen from the table below, there is no short run causality extending from any of the variables to GDP since they are deemed to be insignificant.

Table 5.10: VECM

D_dgcf	L._ce1	-0.244
		(0.78)
	LD.dgdp	0.036
		(0.12)
	L2D.dgdp	-0.189
		(0.96)
	LD.dre	-677.195
		(0.59)
	L2D.dre	-938.855
		(0.61)
	LD.dlec	0.584
		(0.47)

	L2D.dlec	0.145
		(0.10)
	LD.dgcf	-0.259
		(1.18)
	L2D.dgcf	-0.029
		(0.15)
	_cons	0.002
		(0.13)
N		39

Source STATA

a) Error Correction Term:

The error correction term is shown to have negative sign. Furthermore, the error correction term is not significant and hence there is no presence of long run causality from the explanatory variables to dependent variable, GDP. The standard error is 0.78, which is not significant at the 1% or 5% level.

b) Long Run Causality:

The error correction term does not indicate a long run causality extending from explanatory variables to the dependent variable.

c) Short Run Causality:

As seen from the table below, there is no short run causality extending from any of the variables to GDP since they are deemed to be insignificant.

6. Conclusions

The last three decades saw " relatively open trade, rising flows of foreign direct investment, steady growth in the world's major markets, sharply declining transport costs, increased intra-industry trade, and the introduction and spread of information and communication technology" (World Bank, p.23, 2012). According to World Bank, some of these trends are likely to endure, as, for example, developing countries outperformance at least by 2030. The major reasons are continued potential for technological catch up in emerging nations and continued slow growth in developed countries. Developing nations are expected to stand for two-thirds of global growth (China alone represents almost 20%), and half of global output (with China standing for almost 10%) (World Bank, 2012). Despite the rate of economic growth will slow down in developing countries, China included, continued rapid growth in emerging markets will put pressure on global energy supply, natural resources, food, water and the environment. In particular, the surged energy demand of recent years has increased energy security, energy efficiency and environmental concerns, put pressure on suppliers and lead to uncertainties on future supply, investments and policies (IEA, 2015).

Relatively under-exploited oil and gas reserves in Middle East and North Africa will be critical to meet the world's growing appetite for energy, but considerable uncertainty remains on the pace investments and production capacity will take place in those areas. Moreover, renewables will give increasing contribution to world's power generation capacity, in order to fight against climate change, price volatility and other challenges brought by increased energy demand and related greenhouse emissions (IEA, 2015). In fact, renewable will represent the largest source of electricity by the early 2030s, reaching, in 2040, 50% of power generation in Europe, 30% in China and Japan and more than 25% in the United States and India (IEA, 2015).

According to IEA, energy use worldwide is set to grow by almost one-third to 2040, driven primarily by China, Africa, The Middle East and South Asia. Specifically, China and India will be the engine of this growth. Global economic growth and energy demand (and related greenhouse emissions) are used to increase together, but they are going to decouple in the future due to more energy efficient technologies. Economic growth will keep rising while greenhouse emissions and energy use will decrease due to energy efficiency improvements (IEA, 2015).

Recent attractiveness of investing in energy efficiency has been threatened by low oil and gas prices, but, according to IEA, energy efficiency investments are set to keep growing in the medium term even in a low oil price scenario, due to more comprehensive policies that recognize energy efficiency as a cost-effective tool to achieve energy security and climate change challenges. Total investments in the power sector will reach $68 trillion from 2015 to 2040, of which 32% in end-use efficiency. Fossil fuels low prices have also driven the reduction (and in some cases abolishment) of fossil fuel subsidies, facilitating some positive policy changes. According to IEA, government policies are going to play an important role in defining the path of the world energy demand growth and the degree of greenhouse emissions (IEA, 2015).

According to IEA, even if the possibility of oil prices to stay low for a long period cannot be ruled out, they are expected to clear the market again by 2020. Coal supply, which was the fast growing sector in the last decade, will slow down in the next decades, reaching 10% total production increase by 2040. Natural gas production will continue to grow, despite low prices are threatening long-term investments (IEA, 2015).

According to IEA, China is approaching the end of the largest energy demand growth in history. The country's economic growth will keep on rising, but at a slower rate. In the past 15 years, GDP growth and energy demand have grown together in China, but they are going to decouple. Structural changes in the country's economy are going to favor the expansion of services, and thanks to increased energy efficiency, less energy will be required to generate and sustain economic growth. In fact, China represents the country with the highest energy efficiency push in the energy sector and is moving from a heavy industry based economy to a service based one. The energy mix is going to diversify: coal will remain the main energy source but will lose market share, oil demand will slow down while nuclear will increase, since 40% of total power plants under construction are in China. According to IEA, the demand of natural gas in Asia is expected to increase strongly; in fact, developing countries in Asia will account for almost half of the rise in global gas demand and for 75% of the increase in imports. In China, some uncertainties arises from both the supply and demand side, because gas faces strong competition from renewables and coal. Small growth is expected in gas production since China is a small gas producer and in the absence of any regulations, much coal will be used even if it has much more environmental consequences, because it costs less and coal plants are cheaper than natural gas ones. Moreover, renewable energy will continue to have the support of the government, especially wind, solar and hydro (IEA, 2015).

Unfortunately, energy access will remain a problem worldwide. Around 550 million people around the world will remain without any access to electricity, especially in sub-Saharan Africa (IEA, 2015).

This thesis aimed to analyze the impact of renewable energy consumption on China's GDP, because climate and environmental changes have become serious problems and are attracting the interests of leaders from all over the world. In particular, China is one of the main contributor of pollution and greenhouse emissions and should be especially interested in pursue all the ways able to mitigate the situation. The country is committed to renewable energy deployment, investments and political support; signs that the country is moving toward a more sustainable economy are under way, but the path will take much effort.

This study embraced rigorous econometric analysis of the data obtained from official sources to empirically prove the impact of renewable energy consumption over GDP. Firstly, the augmented Dickey Fuller test was taken to check for stationarity of the variables. All the variables appeared to be integrated of order 1, which made possible to take co-integration analysis and the error correction model. Secondly, the instrumental variables regression methodology assumed renewable energy consumption per capita to be an endogenous variable and the other variables as instruments. The analysis shows that renewable energy consumption and gross capital formation have a positive effect on GDP per capita, while energy efficiency has a negative impact. In fact, a 1% increase in renewable energy consumption would lead to 1,714% increase in GDP per capita and a 1% increase in GCF would increase GDP per capita by 0.275 units. On the contrary, a 1% increase in energy efficiency would decrease GDP per capita by 1.9%. To test the validity of the instruments the Durbin Wu-Hausman test and the Sargan Test of Over-identification are performed, and the chosen variable proved to be valid. Thirdly, after establishing co-integration through the Johansen co-integration test, the Vector Error Correction Model was run. The VECM showed long run causality running from the explanatory variable to the dependent variable, GDP, and short run causality extending from renewable energy and energy efficiency to GDP.

This thesis offers an evaluation of the role of renewable energy consumption on GDP per capita. However, the study encountered a number of limitations while carrying out the empirical analysis which need to be considered. Firstly, the availability of China's data is limited because renewable energy deployment is quite recent and some data are not available yet. Secondly, the Johansen co-integrating test and VECM model have some limitations. The test assumes that co-integrating vector remains constant throughout the period of research, which is not always true. It is possible that the long run relationship between the variables, GDP and Renewable energy, changes. This could be due to many factors. Firstly, given the rapid development of the industrial sector in China, the country has access to some of the most advanced technology in the world. Hence, it is likely that technology would have modernized the renewable energy sector. Unfortunately, this thesis does not take into account the technological progress in economic growth. Secondly, the 2008 financial crises and the 2014 plunge in oil prices would have adversely influenced the renewable energy sector, as described in the first two chapters. Thirdly, the growing consensus among the people regarding the issue of climate change could have changed consumer preferences, thereby increasing the demand for renewable energy contrary to the first two points. Lastly, institutional development has not been taking into account as well. China's economic policy has changed manifolds since the last two decades and more and more emphasis is given to the renewable energy sector.

Moreover, there is scope for further research; for example, it would be interesting to study whether renewable energy would have different impacts on GDP of different provinces in China. The inclusion of technological progress and institutional development into the analysis would make this study more precise. Unfortunately, data on renewable energy consumption in China are relatively new and state data are limited, so this research have not been carried out in this thesis.

Climate change and pollution issues are global severe problems, and has been proven that renewable energy consumption would benefit the environment, the health of population and Chinese GDP per capita, showing to be the best solution to address environmental problems.

References

Abdul Jalil, Syed F. Mahmud, Environment Kuznets curve for CO2 emissions: A co-integration analysis for China, Energy Policy, Volume 37, Issue 12, December 2009, Pages 5167-5172.

Abosedra, S., and H. Baghestani. 1991. New Evidence on the Causal Relationship United States Energy Consumption and Gross National Product. Journal of Energy and Development 14, Pages 285–292.

Akarca, A. T., and T. V. Long II. 1980. On the Relationship Between Energy and GNP: A Reexamination. Journal of Energy and Development 5, Pages 326–331.

Angrist, J. & Krueger, A. (2001). Instrumental variables and the search for identification: From supply and demand to natural experiments. Journal of Economic Perspectives, 15, Pages 69–85.

Belloumi, M. 2009. Energy Consumption and GDP in Tunisia: Co-integration and Causality Analysis. Energy Policy 37 (2009), Pages 2745–2753.

BP, Energy outlook-Country and regional insights-China, 2016, http://www.bp.com/content/dam/bp/pdf/energy-economics/energy-outlook-2016/bp-energy-outlook-2016-country-insights-china.pdf

British Petroleum, BP statistical review of world energy, 2016, https://www.bp.com/content/dam/bp/pdf/energy-economics/statistical-review-2016/bp-statistical-review-of-world-energy-2016-full-report.pdf

Chiang, C. L. 2005. Energy Consumption and GDP in Developing Countries: A Co-integrated Panel Analysis. Energy Economics 27 (3), Pages 415–427.

Cragg, J. & Donald, S. (1993). Testing identifiability and specification in instrumental variable models. Econometric Theory, 9, Pages 222–240.

Dalei, N. N. 2016. Determinants of Energy Consumption in Open Economies. In Contemporary Issues in Trade, Environment and Policy, edited by A. Ghosh Dastidar and Y. Gupt, Pages 89–104. New Delhi: Ane Books Pvt. Ltd.

EC (2014), A Policy Framework for Climate and Energy in the Period from 2020 up to 2030, European Commission, Brussels, Belgium.

EIA, China, International energy data and analysis, 2015, https://www.eia.gov/beta/international/analysis_includes/countries_long/China/china.pdf

Erdal, Z., G. Daigger, and B. Forbes. 2008. Energy Future: How To Bridge the Gap between Energy Innovations and Sustainability Using a Whole System Approach. JRB08 - Energy Future Manuscript.

FGE, China Oil & Gas Monthly, February 2015, https://www.fgenergy.com/

Glasure, Y. U. 2002. Energy and National Income in Korea: Further Evidence on the Role of Omitted Variables. Energy Economics 24, Pages 355–365.

Greenpeace (2015), Energy [R]evolution: A Sustainable World Energy Outlook 2015. 100% Renewable Energy for All, Amsterdam, Netherlands. http://english.mofcom.gov.cn/article/policyrelease/Businessregulations/201312/20131200432160.shtml

IEA, CO2 emissions from fuel combustion, 2015, https://www.iea.org/publications/freepublications/publication/CO2EmissionsFromFuelCombustionHighlights2015.pdf

IEA, Energy Supply Security 2014, https://www.iea.org/media/freepublications/security/EnergySupplySecurity2014_PART1.pdf

IEA, Key Gas Trends in 2015, 2016, https://www.iea.org/media/statistics/Keygastrends2015.pdf

IEA, Key World Energy Statistics, 2015, https://www.iea.org/publications/freepublications/publication/KeyWorld2016.pdf

IEA, Model of Short-term Energy Security, 2011, https://www.iea.org/publications/freepublications/publication/moses_paper.pdf

IEA, Natural Gas Information, 2016, http://wds.iea.org/wds/pdf/Gas_documentation.pdf

IEA, oil medium-term market report, 2015, https://www.iea.org/publications/freepublications/publication/MTOMR_2015_Final.pdf

IEA, Renewable Energy Medium-term Market Report, 2015, https://www.iea.org/Textbase/npsum/MTrenew2015sum.pdf

IEA/OECD, World Energy Outlook, 2015, http://www.worldenergyoutlook.org/media/weowebsite/2015/WEO2015_Chapter01.pdf

International Energy Agency and World Bank (2015), Sustainable Energy for All 2015 – Progress Toward Sustainable Energy, World Bank, Washington, DC, USA.

IRENA (2012a), Renewable Energy Jobs and Access, International Renewable Energy Agency, Abu Dhabi, UAE.

IRENA (2015c), REthinking Energy: Renewable Energy and Climate Change, International Renewable Energy Agency, Abu Dhabi, UAE.

IRENA (2015e), From Baseload to Peak: Renewables Provide a Reliable Solution, International Renewable Energy Agency, Abu Dhabi, UAE.

IRENA (2015h), Renewable Energy Prospects: Mexico, REmap 2030 Analysis, International Renewable Energy Agency, Abu Dhabi, UAE.

Kelejian, H. (1971). Two-stage least squares and econometric systems linear in parameters but non-linear in the endogenous variables. Journal of the American Statistical Association, 66, Pages 373–374.

Key, N. & McBride, W. (2007). Production contracts and farm productivity: Examining the link using instrumental variables. In 2007 Annual Meeting, July29-August1, 2007, Portland, Oregon. American Agricultural Economics Association.

Kraft, J., and A. Kraft. 1978. On the Relationship Between Energy and GNP. Journal of Energy and Development 3, Pages 401–403.

Mankiw, N. G. (2003), Macroeconomics, Fifth edition, Worth Publishers, London, UK.

Masih, M. M., and R. Masih. 1997. On the Temporal Causal Relationship Between Energy Consumption, Real Income and Prices: Some New Evidence From Asian-Energy Dependent NICs Based on Multivariate Co-integration/Vector Error Correction Approach. Journal of Policy Modeling 19, Pages 417–440.

Mathur, S. K., R. Arora, I. Ghoshal, and S. Singh. 2015. Domestic Energy Consumption and Country's Income Growth: A Quantitative Analysis of Developing and Developed Countries Using Panel Causality, Panel VECM, Panel Co-integration and SURE. Journal of Quantitative Economics:1–30. DOI - 10.1007/s40953-015-0021-4.

Michael Klare, Resource Wars: The New Landscape of Global Conflict, New York: Owl Books, reprint edition 2002.

Michael Klare, The Race for What's Left: The Global Scramble for the World's Last Resources, Metropolitan Books, first edition 2012.

Michael Klare, Twenty-First-Century Energy Wars**:** Global Conflicts Are Increasingly Fueled by the Desire for Oil and Natural Gas and the Funds They Generate, 2014.

Ministry of Commerce of People's Republic of China, Renewable Energy Law of People's Republic of China, 2013.

OECD (2011), Towards Green Growth, Organization for Economic Cooperation and Development, Paris, France.

Perry Sadorsky, Renewable energy consumption and income in emerging economies, Energy Policy, Volume 37, Issue 10, October 2009, Pages 4021-4028.

RAP, Recommendations for Power Sector Policy in China, 2013, http://www.raponline.org/wp-content/uploads/2016/05/rap-nextstepspowersectorpolicyinchina-en-2013-oct.pdf

Soytas, U., and R. Sari. 2003. Energy Consumption and GDP: Causality Relationship in G-7 Countries and Emerging Markets. Energy Economics 25, Pages 33–37.

Stock, J.&Yogo, M.(2005). Testing for weak instruments in linear IV regression. In Testing for Weak Instruments in Linear IV Regression. In: Andrews DWK Identification and Inference for Econometric Models, New York. Cambridge University Press, Pages 80–108.

Tao Song, Tingguo Zheng, Lianjun Tong, An empirical test of the environmental Kuznets curve in China: A panel co-integration approach, China Economic Review, Volume 19, Issue 3, September 2008, Pages 381-392.

UN DESA, World Population Prospects, 2015 revision, https://esa.un.org/unpd/wpp/publications/files/key_findings_wpp_2015.pdf

UNEP (2011), Towards a Green Economy: Pathways to Sustainable Development and Poverty Eradication, United Nations Environment Programme, New York, USA.

WEF, Global Energy Access and security, 2016, http://reports.weforum.org/global-energy-architecture-performance-index-report-2016/energy-access-and-security/

World Bank, China overview 2030, 2012, http://www.worldbank.org/content/dam/Worldbank/document/China-2030-complete.pdf

World Bank, China Overview, 2014, http://www.worldbank.org/content/dam/Worldbank/document/China-2030-overview.pdf

Xinhua News Agency, 2015, http://news.xinhuanet.com/legal/2015-08/30/c_128180129.htm

Ying Fan, Lan-Cui Liu, Gang Wu, Hsien-Tang Tsai, Yi-Ming Wei, Changes in carbon intensity in China: Empirical findings from 1980–2003, Ecological Economics, Volume 62, Issues 3–4, 15 May 2007, Pages 683-691.